A TREATISE

ON

NAVAL ARCHITECTURE

AND

SHIP-BUILDING

OR

AN EXPOSITION OF THE ELEMENTARY PRINCIPLES INVOLVED IN THE SCIENCE AND PRACTICE OF NAVAL CONSTRUCTION.

COMPILED FROM VARIOUS STANDARD AUTHORITIES.

BY
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TO

Vice-Admiral David D. Porter, U. S. N.,

UNDER WHOSE AUSPICES AS

SUPERINTENDENT OF THE NAVAL ACADEMY,

THE IMPORTANT STUDY OF NAVAL CONSTRUCTION

WAS EMBODIED AS PART OF THE REGULAR COURSE AT THAT INSTITUTION,

This Compilation is Respectfully Dedicated.

PREFACE TO THE SECOND EDITION.

THE matter contained in this volume has been mainly gathered from such standard works as those of Scott Russell, Rankine, Murray and Knowles, with some assistance from Fairbairn, Fishbourne, Marrett and Peake—the object in view being to furnish a text-book for the use of the students at the United States Naval Academy.

A naval officer of fair mathematical ability can readily make himself familiar with all the essential principles governing the design of a ship, as well as the method of making the necessary calculations; but to become a naval constructor is quite another thing, and needs the long and patient apprenticeship of the "mould-loft" and ship-yard. Yet there is no more mystery about naval construction than about steam-enginery; and any intelligent officer may soon be theoretically, at least, conversant with both, while the importance of acquiring such knowledge, in these days of progress, is self-evident.

In accordance with these views, this compilation has been made, and is now submitted for the consideration of my brethren of the naval service.

COLD SPRING, N. Y., June, 1869.

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Naval Architecture.

NAVAL ARCHITECTURE.

CHAPTER I.

THE SCIENCE OF NAVAL ARCHITECTURE.

THE Science of Naval Architecture treats several chief problems:

1st. How to make a ship swim.

2d. How to make her carry heavy weights.

3d. How to make her stand upright when the waves or the winds try to upset her.

4th. How to make her obey the will of her commander.

5th. How, in addition to all these, to make her go easily through the water at high speed.

Subordinate to the above are the following:

6th. How to give a ship a given draft of water and no more; *first*, when she is light, and *second*, when she is laden.

7th. How, with the given draft of water, to prevent her oversetting when she is light, and rises high out of the water; and how to prevent her being overturned by the great burden laid upon her when she is heavily laden.

8th. How, when a heavy sea strikes on one side of the ship, to prevent it from rolling into her, without, at the same time, heeling her so far over as to expose her to danger on the other side.

9th. How to make her bow rise to the sea, so that the waves may not roll over her deck, without, at the same time, making her rise so far as to plunge her deeply into the succeeding hollow, and make her uneasy and slow.

10th. How to make her stern of such a form that, when *scudding*, the sea shall not break over her poop.

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11th. How to make her so stiff on the water that the pressure of the wind on her sails shall not upset her, without, at the same time, giving her so much stiffness as to endanger her masts by the jerk of the sea.

12th. How to make her turn quickly, and in short space, in obedience to her rudder, no matter how fast she may be going; and how to make her weatherly.

13th. How, in combination with the foregoing, to make her fast before the wind, against the wind, across the wind, when she is laden, when light, when the sea is smooth, and when the sea is rough.

These are some of the undertakings with which the science of the naval architect must cope. They are all matters the principles of which belong to science. They are all matters of forethought and calculation, for which exact results are to be sought and ascertained, long before the ship-builder can even set about his work. They form the *science* of Naval Architecture, as distinguished from the *art* of Ship-building.

CHAPTER II.

THE ART OF SHIP-BUILDING.

THE Art of Ship-building consists in giving to the materials of which the ship is to consist all the forms, dimensions, shapes, strengths, powers and movements necessary to make them fulfill and comply with the conditions resulting from the calculations of the naval architect.

1. To make the ship swim, she must be tight and staunch everywhere, so as to take in no water through her seams or fastenings.

2. To make her swim so deep, and no deeper, the weights of *all* her parts, taken together, must be equal to the measure the naval architect has given, and which he has called her "*light displacement.*" This done, it is the business of the naval architect, and not of the builder, to see that a given load placed in the vessel will not sink her beyond her given load draft.

3. To make the ship strong enough to carry her load without straining herself is part of the art of ship-building: the quantity of material put into the ship being limited by the naval architect, it belongs to the craft of the ship-builder to select the fittest quality of material, to put it in the most effectual place, and to unite the pieces in so substantial a manner that no piece, when strained, shall part from its neighbor, but that every part shall not only do its own work, but be able to help, in need, every other part, so that all, joined together, shall form one staunch whole.

4. In making the ship strong enough for the work she has to do, the builder must preserve throughout the whole such a just distribution of the weight of the parts as that she shall not be too heavy at the bottom, nor at the top, nor at the bow, nor at the stern, but that the weights of the parts, in their places, shall so accurately corre-

spond to the nature of the design that there shall be *a perfect balance of weight around the exact centre* intended by the architect. This is necessary in order that the trim of the vessel at the bow and the stern, and her *stiffness*, or power to stand upright, shall turn out to be what is meant in the plan. The best designs have failed through unnecessary weights being, in the execution of the work, placed where they did harm, instead of where they could have done good. *Disposition of weight*, therefore, in the hull is an important point in practical ship-building.

5. The geometry of ship-building is one of the most important branches of the ship-builder's art, and the exact fitting and execution of parts truly shaped is one of the best points in which he can show his skill. The design to be executed having been put into his hand, the ship-builder has first to lay it down on the *mould-loft floor* to its full size; next he has to divide and show on this drawing, in its full size, every part of which the ship is to consist; of each of these parts a separate and independent drawing has now to be made, and a shape or *mould* made from this in paper, in wood or in iron. To this mould the material of the ship, whether pieces of iron or wood, has to be *exactly* shaped; and these independent drawings or moulds must show every face and every dimension of each part. When it is remembered that in every ship, consisting probably of several thousand parts, generally speaking no two are alike, and only two, at most, resemble each other—namely, the counterpart pieces on the two opposite sides—and that every one of those pieces has probably four sides, each with a different curve from the other, and containing possibly one hundred perforations,* which must have precise positions with reference to these curves, it will be seen that making the measurements and drawings is a labor which must be performed with the utmost precision and intelligence, in order to have good, honest and reliable work, and requires no small amount of geometrical skill from the builder.

6. The art of the ship-builder frequently extends not only to the mere construction of the ship's hull, but also to the construction, or fitting in, of all those separate things which are not parts of the ship proper, and yet without which she cannot be sent to sea. There are parts which, if not made by the ship-builder himself, must be so

* See Iron Ship-building.

provided and fitted as if he had himself made them. A ship is not complete unless she has a *rudder* and *steering mechanism*, *compasses* and their *binnacles*, *anchors* and their *cables*, *capstans* and *windlasses* to raise and lower the anchor, *boats* and *davits*, and the *tackle* to raise and lower them, *masts* and *yards*, and *standing rigging* and *running rigging*, and *sails* and *blocks*, and all the means of placing, fastening, supporting and working them. There must be, also, *pumps* to work in case of accident, besides a large inventory of smaller things, all to be found before a ship is complete or fit to go to sea. All these, for the most part, the ship-builder has to find; and, while it is a matter of doubt, opinion, custom, or special contract, how many, and which of them, are parts of the hull, or parts merely of the equipment of the hull, or of stores for her voyage, yet it is always in the ship-builder's province to consider fully all these things, and so to arrange for them that no unnecessary difficulties may be interposed in the way of those who have to supply and to fit them. Generally speaking, the rudder and steering-gear, the mechanism for fixing and working the anchors and cables, the masts and spars, and the means of attaching the rigging and working the sails, and boats and the ship's pumps, are reckoned part of the ship proper, to be done in the ship-builder's yard, while the rigging itself, the sails, the anchors, the cables, the compasses, and all the minor inventory are reckoned as "*Equipment*" only. It is part, therefore, of the craft of the ship-builder to understand thoroughly, as well as to execute, that part of the equipment and the fitting which is reckoned as part of the hull.

7. But it is the finishing-stroke of the ship-builder to place his vessel safely in the water. To this part of his skill belong all the traditions of launching. In this the traditional ship-builder excels; for science has taught him nothing. The knowledge of launching has grown, and, with the odd variations in form, there is a wonderful unity in substance, even in different countries. The construction of the *cradle* in which the ship is committed to the deep, of the *ways* which carry her from the shore into the water, of the slope on which she glides so smoothly down, even to the mixture of soap and grease which lubricates her passage,—all is known by fixed tradition; and so skilled has the long progress of practice rendered this finishing-stroke of art, that constructors, when ordered to lengthen a ship already built, have been known to cut her in two, and to give to the

after part so gentle a launch, that it stopped exactly when it had reached the point of distance from the fore part to which the lengthening was meant to extend. So, also, when an attempt was made, as in the launch of the "Great Eastern," to bring in other than ship-building skill, the result was an extravagant failure.* This, therefore, is one of the points in which the ship-builder cannot do better than adhere to his traditions. But along with these general principles of matured experience, there is enough variety of practice to leave the ship-builder a wide choice. Some nations launch with the bow, some with the stern foremost, some broadside on. Some launch with the *keel* resting on the *ways*, the *bilges* clear; others launch with the bilges on the ways, and the keel clear; but in all these different modes a tolerable attention to the precepts of tradition will enable the ship-builder to execute this "tour de force" with a fair certainty of success. In England, some have even ventured to carry this so far as to launch steamers with masts up, rigging fitted and sails bent, their equipment on board, their engine and boilers fitted in them, their fires lighted and steam up; and they have left the ship-yard from the launch-ways in perfect safety, propelled by their own steam.

* This vessel was launched, broadside on, from the Isle of Dogs in the Thames river.

CHAPTER III.

THE METHODS OF PROPELLING SHIPS.

THE naval architect, the ship-builder and the marine engineer represent three classes of professional skill, all of which go to the achievement of a perfect steamship. The duties of all must be successfully performed, in order that the duty of the steamship may also be performed successfully. It is not necessary that the three duties should be performed by three separate men, but all are essential. They may even be all performed by one man, and he may first form the design of the whole, then build the ship, and, lastly, construct the engines;* but, in theory, it is better to keep these parts separate, although, in practice, they cannot be too closely united.

Steam navigation, or the propelling of a ship by steam, is effected by means of three instruments. The source of the entire steam-power of a ship resides in the *boiler*, and it is the power of this boiler to produce steam which ultimately determines the question of the power and speed of the ship. Boilers, therefore, are the first consideration in marine engineering. The second part is that which applies the steam made in the boiler to the purpose of producing mechanical motion, and forms what is called the machinery, or *steam engine.* It is by the engine that the steam is turned to use and worked; but engines accomplish their purpose differently; they all waste some steam in moving themselves and not in moving the ship; and some waste much steam and do little work. It is difficult to know how much is wasted, even by the best marine engines, for some of great reputation waste more than others of less. The marine engineer must see that he effects the least possible waste, and gets

* This is the case in the French navy, where the chief constructor is also the constructing engineer.

out of his engines the maximum possible effect; but this result he can only know by taking careful measures, not merely of the work done by the steam in the engine, but also of the work given out by the engine after working itself. It is his duty, therefore, thoroughly to master all these points.

The third instrument of steam navigation is that by which the ship is made to move. The boiler makes the steam, and the steam moves the engine merely, but not the ship. The engine has to move something, which, by moving the water, shall compel the ship to move. Though all three instruments move the ship, or tend to move it, it is only this last which directly touches the water, and which moves it and the ship; it is called the *motor* or *propeller*. The steam propeller is, therefore, the third instrument employed in steam navigation. The kinds of propellers are many and various; some being a single instrument, as a *screw propeller*, and the *paddle-wheel propeller*, when used singly in the stern of a steamer, or in the centre of a double or twin vessel. There are also *double propellers*, as where *twin screws* are used in one vessel, or where two paddle-wheels are used on a vessel. There is also the *jet propeller* (both steam and water), the *chain propeller*, the *stern propeller*,* and a host of others not now in practical use. There are propellers out of the water and under water, at the sides and the bottoms of ships, at the bow as well as at the stern; and almost every place that can be named has been selected by *somebody* for a propeller. It is the business of the practical marine engineer to devote his attention *to those modes of propelling which are in general use*. He must examine the laws which govern all steam propulsion, and thus learn to measure the degree in which it can be made perfect, and the degree in which, in the nature of things, it must remain imperfect, aiming continually to get as near to perfection as possible. He must never forget, however, that it is absolutely impossible to attain this perfection, since water slips away from the propeller, and that, in thus escaping, it carries off power in the very act of motion. This power so lost is called loss by *slip*. A scientific knowledge of the laws of propulsion enables him to judge when this slip runs to waste merely, and when, on the other hand, it is no more in quantity than is necessary to produce the propulsion of the vessel. In order to propel the vessel, the propeller must take

* This has been called the *steam oar*.

hold of and push the water; the water *will* slip away from its hold, but in the very act of slipping the propeller must dextrously lay hold of it in just so many instants of time as to take out of it the greatest push with the least slip; *no* slip is nonsense—*much* slip is folly; as little slip as is practicable may be fairly demanded of the competent marine engineer.*

Besides propulsion by steam, there is another method of propulsion, the subject of an entirely distinct profession from that of the engineer and architect; that is, driving ships by sails, instead of steam. This is properly the vocation of the seaman; and it is his business to know and say how he would best like all arrangements of the masts, sails and yards, so that he and his crew can best handle and manage them. But there is one part which the naval architect should do: he should thoroughly study the *balance of sail,* as every ship, according to the qualities of her design, will carry her sails badly if they have not been perfectly balanced in conformity with the peculiar properties, proportions and dimensions of each ship. It is the naval architect's business to provide the seaman with a perfect balance of sail; and it is the latter's province to know how to use it, and handle his ship properly when he has got it. Balance of sail, therefore, must be studied along with *balance of body, draft of water, trim* and the other original mathematical elements of the design of a ship.

There is, finally, another point in which the professions of the seaman and naval architect touch each other very closely. This is, the *trim* and *stowage* of the ship; and the reason why the business of the sailor here touches so closely upon that of the architect is, that a little ignorance or folly on the part of the seaman can neutralize and undo all that the naval architect and ship-builder have done for the good qualities of the ship.

If he has not knowledge enough of the place where the *centre of balance of weight* of the ship is put, and does not contrive to keep it where it ought to be, but fills the ship with improper weights at improper places, he will ruin the performance and mar the reputation of the finest ship in the world.

But few seamen know these things thoroughly, and thereby acquire reputation both for themselves and their ships. With an ignorant

* The term Engineer is here used to denote the designer or builder of an engine.

officer it is impossible to know whether the ship be a good or a bad one.

Now, although it may not be possible for a sailor to be also a naval architect, inasmuch as each profession demands the study of a lifetime to learn it, yet a sailor *can learn and should know* enough of the architectural points of a ship to turn them to the very best account; and it will be necessary, therefore, farther on, to investigate some of those points common to the seaman and naval architect.

CHAPTER IV.

DIFFERENT CLASSES OF SHIPS FOR PEACE OR WAR.

Although the principles which guide the naval architect in the construction of ships, and govern their behavior in the sea, are fixed and invariable, it will be the use the ship is to be put to which must govern the naval architect in the application of those principles to practical use. Ships employed for purposes of commerce, for mere pleasure or for purposes of war must be as different in their construction as in their objects, and, accordingly, the different classes of ships, designed for such different uses, give rise to distinct departments of naval architecture.

For the purposes of war, the conditions which the naval architect has to fulfill are widely different from those he has to meet in the design of a merchant vessel. The principles which guide him are the same, yet the points of practice are in some respects easier, in others more difficult. The merchant ship, in its voyages around the world in search of freight, has to undergo all sorts of conditions of emptiness and fullness, of lightness and deepness of draft, and has to stow all sorts of cargoes, with every variety of bulk and of specific gravity. Sometimes she has to carry a heavy deck-load with little in her hold, and at other times, so much weight, so deep in her bottom, that it would seem to be almost impossible to reunite two such opposite uses in the same ship.

The man-of-war has but *one* duty—to convey a known weight of guns and of men to a known place; and this kind of work, being so exactly known, ought to be infallibly and exactly done. That a ship-of-war, under such known conditions, should ever have a mistake made, or an inaccuracy found, in her draft of water, her stability or her speed, might seem therefore disgraceful if it were not, unhap-

pily, too common. The explanation which is sometimes given is, that those whose business it is to order these ships are unable to settle, beforehand, what they are intended to do, and that they are generally afterward ordered to do exactly that for which they were not originally designed.*

There is one peculiarity which belongs equally to both kinds of vessels—that, whatever her load may be, she must, above all things, be *fast.* In commerce, time is money; in war, time is victory; and victory, the sole object of war, is entirely in the hands of the man who has the choice when and where to meet his enemy. This is an axiom, and needs no argument.

To have *easy movements* in bad weather is also the indispensable requisite of a good ship of both sorts; but the quality which constitutes a good sea-going vessel may have to be given to them in different ways.

In a merchant ship, the lading of the ship being variable, and its arrangement entirely under the disposition of the shipmaster and owner, the internal adjustment of weights may be so made as to give her every variety of quality. In the ship-of-war, on the contrary, the disposition of weights being both invariable and inevitable, and fixed by the indispensable purpose of the vessel, the sea-going qualities must be given by the naval architect alone, in his original design; and the subsequent adjustment of the qualities of the ship, by disposition of weight, can be carried out only within narrow limits. It may happen, and it does happen, that the necessary disposition of the greatest weights of the ship-of-war are hostile to the sea-going qualities of the vessel and to the desire of the naval architect. The battery of the ship may be a great weight, acting high out of the water; and that will be a great difficulty, acting with great power against him.

It may be that he has to carry heavy loads of iron armor at great distances from those centres of his ship around which he is anxious to have the most complete repose, even at the time when the efforts of the sea are greatest to put those weights into violent motion; yet these very causes of bad qualities for the sea-going vessel may form a specific virtue for the fighting vessel. The successful reconciliation

* This was the case with the "double-enders" during the late war—they were designed for river service, but were employed at sea, on blockade.

of such antagonism is the highest triumph of the skill of the naval architect in the design of a ship-of-war.

A third condition of both kinds of vessel, differently carried out, according to the diversity of use, is what it will be necessary to call "*capacity of endurance.*" In a merchant ship, sailing or steamship, this means ability to carry a large freight, to carry it at small cost, within an assigned time. To do this, a merchant ship should maintain her given speed with regularity, independently of weather, should do so at moderate wear and tear in all the elements of her first cost, and should effect, at the same time, great economy in all the usable and consumable stores which form a great part of her floating equipment and provisions, and on which, in great measure, the profit or loss of a voyage depends.

For a ship-of-war the capacity of endurance must be of a nature somewhat different. She must certainly have the power of arriving with certainty at the place where she is wanted, independently of weather; but her sustaining power may often consist in her ability to keep herself in good fighting order for a long time, at a great distance from home, and, without exercising her greatest power, to be in a condition to do so at a moment's warning, without such exhaustion of her resources as may leave her helpless at a critical moment. This is a kind of economy of a very different nature from that of a merchant ship, but must be originally conferred on the vessel by the forethought of the naval architect, and must be studied and carried into effect by the wisdom and knowledge of the officer in command.

There is another branch of professional knowledge and skill, without some acquaintance with which the naval architect cannot design a ship-of-war. A ship that cannot work and fire her guns when wanted may have every other good point, and be worthless for want of that. The architect must know, then, what is necessary, in order that the crew may work the guns to the greatest advantage, and thus aid in achieving victory.

Should two ships engage in a rough sea, the mere fact that the guns in one could be better handled than those in the other in that state of the weather, might be the turning-point of victory.*

Ignorance of this point, therefore, on the part of the designer of

* So far back as the time of the celebrated Chapman, constructors were keenly alive to the importance of this point.

the ship, would be failure, and he must have the knowledge of all the points relating to the placing and working of the guns before he begins his design—*not*, as we frequently see, *after* the ship is built, and when it is too late.

But magnificent-sailing men-of-war must be considered now as finally dismissed from service. The line-of-battle-ship, fighting under canvas, is no match for the little iron-clad gunboat. It is probable that no such vessel will ever again enter into action. The production of the fleets of the future is at present a race of competition, of science and of skill between the great maritime powers of the world. Who will win this race must depend much upon the wisdom, forethought and capacity of the men who preside over the navy of each country.

Taking this view of the subject, it becomes a matter of paramount necessity that the young officers who will eventually command our ships and lead our fleets should thoroughly understand the conditions which regulate and control the designs of the steam fleets of modern warfare, and the methods used in their practical construction; and it is hoped that this knowledge may promote the advancement of the national interest, both political and mercantile.

CHAPTER V.

GENERAL CONDITIONS OF THE PROBLEM OF NAVAL ARCHITECTURE.

THE professional duty of the naval architect being to frame and complete the *design* of a ship—the word "design" implying plan, use, or purpose—therefore the first duty of the architect is to ascertain accurately, note exactly and conceive clearly the intention and purpose which the vessel is designed to fulfill.

If the case under consideration is that of a merchant vessel, to the owner, then, the naval architect must apply for a clear understanding of all that the ship is meant to be and to do; and therefore the following questions may be of service in eliciting the information necessary before commencing the design of the vessel:

The owner must be asked—first, what he wants his ship to do? He may answer: To trade between New York and New Orleans.

2. What kind of trade he proposes to carry on?—*Answer.* A miscellaneous trade, partly merchandise, partly passengers.

3. What quantity, bulk and nature of cargo?—*Ans.* 500 tons of dead weight; 25,000 cubic feet of bulk, for cargo in the hold.

4. What kind and number of passengers?—*Ans.* 25 first-class, 20 second-class passengers.

5. What sort of voyage?—*Ans.* Once a month, stopping nowhere on the way.

6. At what speed?—*Ans.* An average of 8 knots.

7. Carrying much canvas or little?—*Ans.* To depend mainly on steam, the sails being auxiliary.

8. At what estimated cost per voyage?—*Ans.* $1.75 per mile.

9. How much is the owner prepared to pay for his vessel?—*Ans.* $125,000.

10. How much is the owner prepared to pay for a more or less durable ship? how much for more or less durable engines and boilers? and how much for a more or less complete equipment?—*Ans.* Ship to be classed twelve years, A No. 1; engines and boilers to be those least likely to fail when wanted, most economical in repairs and consumption of fuel; and 15 per cent. preference to be allowed on the price of good engines and boilers over indifferent.

11. What draft of water?—*Ans.* Load draft not to exceed 15 feet; no other limit as to dimensions.

12. What class of shipmasters and engineers to be employed? *Ans.* The best master and engineer, without reference to salary. (The owner will do well to select his master and engineer, and put them in communication with the naval architect before the ship is built.)

13. Is the ship to be confined exclusively to this trade, or may she have in future to be employed on other voyages?

Now from the master and engineer the architect may receive information on the following questions:

14. What is the true length of the voyage according to the course usually followed?

15. What has been the average performance of any known vessels on the line?

16. What would require to be the maximum speed of a vessel in good sailing trim in order to realize an average working speed of eight knots an hour on the voyage?

17. What sort of ships and engines have hitherto been employed to do this sort of work?

18. With how many officers and hands as crew, and how many in the engine-room, is this ship proposed to be worked?

19. Besides the room required for cargo, for passengers and for attendants, how much is to be reserved for machinery, for coals, for ship's company, for ship's stores, for provisions and equipment?

20. What is the exact nature of the equipment required for this peculiar voyage?

21. What are the weights to be carried under these respective heads?

These are the conditions of the problem, without which, as preliminaries, the design of the ship cannot even be begun, and all of

them must be sought and given to the naval architect at the outset, in order to prevent much of his work being mere waste.

The result of all these inquiries will lead him to this most important and primary issue, which may be said to determine the chief characteristic of his ship—namely, the *burden* she must carry and the *bulk* she must stow. In addition to her own powers to swim, she must have power to carry; and the total weight she must carry when full is 1000 tons. But the vessel herself will weigh a known quantity—a quantity either suggested to him by some vessel he already knows, or which he must find out by calculation; but suppose it be assumed that his ship will weigh 500 tons in addition to the 1000 tons before stated.

The ship, therefore, with her equipment, her freight and her stores, gives a dead weight to be dealt with in the design of 1500 tons. This is technically called "the total deep-load displacement of the ship," and forms the first condition of the problem. It is the dead weight to be carried; and the question is, How best to carry it? This is treated of under the head of "Displacement."

The foregoing, drawn from the necessities of the merchant service, will serve also to suggest a similar series of requisitions to be made before commencing the design of a vessel of war. The nature of the service on which a man-of-war is to be employed, the harbors she is to enter, the length of a voyage on which she may be sent, the number of her crew, the weight of her guns, ammunition, equipment and stores, and, for a steam vessel, the power required to drive her at a given speed, and the coal required to take her a given distance, with a multitude of particulars quite as minute as those given in the case of the merchant vessel, must be obtained by the naval architect before he can commence his design.

It is sometimes the practice to ask a designer to build a ship-of-war, and to tell him that it will be time enough to consider all the details of her armament, equipment, special construction and destination after the design has been completed and while the ship is in progress. This is a fallacy: it will not be time enough; it will be too late.

Most of the failures in this country have been produced by building the ships first and settling what they were to do afterward. The naval architect who respects his profession should never design his

ship until all the requisite data have been given him. Without this there can be no science of naval architecture, and no plan of a ship worthy of being called a design.

But when these have been obtained, he should arrange them, reconcile them, and finally determine them by setting them out in a formal manner, in what may be called the

Scheme of Conditions of Construction,

which forms afterward a programme of work to be done in forming the design of a ship.

Scheme for the Construction of a Merchant Steamer.

	Bulks. Cubic feet.	Weights. Tons.
A miscellaneous cargo	25,000	500
Passengers, 25 first-class	6,250	.....
" 20 second-class	3,000	.....
Engines and boilers (with water)	7,500	150
Fuel and engineer's stores	10,000	200
Equipment and sea stores	7,500	150
Ship's hull and internal fittings	17,500	350
Provisions and water	2,500	50
Officers, engineers, servants and crew	7,500	10
Spare capacity and weight	3,250	90
Gross capacity and weight	90,000	1,500

Voyage of 1500 sea miles (knots).

A mean speed of 8 knots.

Load draft........ 15 feet.

Speed in smooth water........ 10 knots.

Fuel per mile........ $1\frac{1}{2}$ cwt. (168 lbs.)

Ship's company	Officers	5	30 hands.
	Engineer and assistants	3	
	Crew and coal-heavers	22	

Time of single voyage, eight days.

Scheme for a Man-of-war Screw Steamer—(1st-Rate).

	Bulks. Cubic feet.	Weights. Tons.
Engines and boilers (with water) } Engineer's stores }	50,000	1,000
Fuel	50,000	1,000
Guns, 50	100,000	300
Powder and tanks, including space for light rooms	6,000	50
Shot and shell	2,000	100
Ordnance stores	3,600	50
Water for four weeks, for 500 men	3,500	75
Bread for six months, for 500 men	4,500	50
Other provisions for six months	7,000	100
Masts, yards, rigging and sails	....	155
Spare sails and sailmaker's stores	3,000	30
Navigator's stores } Boatswain's stores }	2,000	25
Carpenter's stores	1,300	20
Boats	....	12
Chain cables	1,500	65
Anchors	....	22
Officers' stores	2,500	10
Paymaster's and marines' stores	2,000	16
Galley and condensers	600	12
Officers, crew and effects (500)	....	60
Shaft alley	5,000	...
Wing passages	5,000	...
Ventilating passages	2,000	...
Mast-rooms and hatchways	2,800	...
Spare bulk and weight	24,000	118
Weight of ship's hull	....	3,000
Total capacity and weight	280,000	6,300

For the calculation of the displacement of a man-of-war, the following may be useful:

	Weight.	
One XI-inch Pivot gun, with ammunition and equipment complete (see Table I.)	52,935	lbs.
One IX-inch gun, etc., complete (Broadside carriage)	22,656	"
One VIII-inch " " "	16,342	"
One 32-pounder " " "	11,054	"
One 100-pounder Rifle gun, complete (Pivot carriage)	34,153	"
One 60-pounder " " "	19,435	"
One 60-pounder " " (Broadside carriage)	15,630	"
One man, with clothes and other articles	0.11	tons.
Provisions, with *tare* and fuel for cooking, etc., for one month	0.07	"
Water, with *tare* for one man for one month	.0.14	"
Steam engines with boilers, and water in boilers, coal bunkers and stores per *nominal* horse-power	0.71	"
Coal for one *nominal* horse-power in 24 hours	0.15	"

In the old sailing frigates, *ballast* was carried to ensure stability. This was sometimes twice the weight of the guns. Ships with full steam-power do not need ballast for stability, yet a little is usually carried for trimming ship.

TABLE I.

Weights of Guns, Carriages, Ammunition and Equipment Complete—U. S. Naval Ordnance.

	XI-INCH (PIVOT).			IX-INCH (MARSILLY CARRIAGE).			VIII-INCH (MARSILLY CARRIAGE).			32-POUNDER (BROADSIDE).			100-POUNDER (PIVOT).			60-POUNDER (PIVOT).			60-POUNDER (BROADSIDE).		
	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.	No. of.	Weight of each.	Aggregate Weight.
		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.		lbs.	lbs.
Gun	......	....	16,000	......	....	9,000	......	....	6,500	......	....	4,500	......	....	9,700	......	......	5,400	......	......	5,400
Carriage	......	....	9,310	......	....	1,250	......	....	*1,000	......	....	*850	......	....	8,416	......	......	3,315	......	......	900
Service charges of powder	175	{ 20.1 / 15.9 }	2,710	110	{ 13.1 / 10.9 }	1,133	110	7.	770	110	6.	660	175	8.	1,400	175	6	1,050	175	6	*1,050
Saluting " "	50	6.	300	50	5.	250	50	4.	200	50	4.	200									
Shell, loaded / " unloaded	90	135.5	12,195	65	73.5	4,778	65	52.75	3,426	65	26.5	1,722	95	80.	7,600	95	50	4,750	65	50	4,750
Shrapnel	35	141.	4,935	15	75.	1,125	15	52.	780	15	32.	480	25	*80.	2,000	*25	*50	1,250	15	*50	750
Shot	10	166.	1,660	10	90.	900	10	65.	650	10	32.5	325	15	70.	1,050	15	60	900	10	60	600
													Round shot.								
Grape	5	125.	625	5	74.1	370	5	53.25	266	5	33.5	167	15	32.5	487	15	18	270	10	18	180
Canister	10	120.	1,200	5	70.	350	5	50.	250	5	30.	150									
Total	......	....	48,935	......	....	19,156	......	....	13,842	......	....	9,054	......	....	30,653	......	......	16,935	......	......	13,630
Shell-boxes, Junk-wads, Powder-tanks, Breechings, Rammers and Sponges, Tackles, &c. *	......	....	4,000	......	....	3,500	......	....	2,500	......	....	2,000	......	....	3,500	......	......	2,500	......	......	2,000
Grand Total	......	....	52,935	......	....	22,656	......	....	16,342	......	....	11,054	......	....	34,153	......	......	19,435	......	......	15,630

* Estimated.

The number of men may be taken as follows:

TABLE II.

Pivot Guns.						Broadside Guns.						
XI-inch } X-inch } 16,000 lbs.	X-inch, 12,000 lbs. 64-pounder, 106 cwt.	IX-inch, 9000 lbs. 100-pounder Rifle.	60-pounder Rifle.	30-pounder Rifle.	20-pounder Rifle.	IX-inch, 9000 lbs. 100-pounder Rifle.	VIII-inch, 63 cwt.	VIII-inch, 6500 lbs. VIII-inch, 56 cwt.	32-pounder, 57 cwt.	32-pounder, 4500 lbs. 32-pounder, 42 cwt. 60-pounder Rifle.	32-pounder, 33 cwt. 30-pounder Rifle.	32-pounder, 27 cwt. 20-pounder Rifle.
24	20	16	10	8	6	16	14	12	12	10	8	6

The additional men for powder division, master's division, engineer's and other divisions must be calculated from the tables in the Book of Allowances. A ship to carry a specific battery must have the total number of persons in accordance with that battery, together with the extra number for her power as a steam vessel, fully ascertained before a design can be commenced. The Book of Allowances, United States Navy, gives all the requisite data for finding *full* complement. For steam merchant vessels the following is an *approximation*. Sailing vessels carry somewhat smaller crews.

Cargo in tons.	Number of men as *crew*.	Cargo in tons.	Number of men as *crew*.
100	8	600	22
150	9	800	28
200	11	1000	32
300	13	1500	45
400	16	2000	60
500	20		

CHAPTER VI.

DISPLACEMENT—HOW TO MAKE A SHIP SWIM AND CARRY.

IT was Archimedes, the philosopher, who discovered the law of displacement; or that *floating bodies* displace a weight of water exactly equal to their own weight, and it is owing to this discovery that the principles of flotation are understood.

The law of displacement consists of two parts: *first,* that a body placed under water displaces as much water as its own bulk; *secondly,* that it floats when it weighs less than the water it displaces.

This principle, although the foundation of ship-building, has also a great many other useful applications. If you have anything of awkward shape, and you want to measure its bulk—say a piece of wood or a model of a boat—take a vessel of water large enough to hold it; place it where it may run over, and where the overflow of the water can be retained; put the substance under water and measure the overflow. That in gallons, or in cubic inches, is the exact bulk of the body. For rough and ill-shaped substances there is no better way than this. Bodies, therefore, which are designed to float in the water must be so designed that when they are put into the water sufficiently far to swim just so much out of the water as is intended, the part in the water shall be of the exact size necessary to displace the quantity of water intended, while the body which floats shall be of the exact weight of the water it is designed to displace. In short, displaced bulk for immersed bulk, and weight for weight, the floating body and the water, whose place it occupies, must be identical.

Let us see what will happen if this be not accurately done. Suppose the bulk of the body has been made too small for the weight which it is intended to carry,* then the vessel will sink deeper into

* The "*light-draft*" monitors built during the late war are instances of an error of this kind.

the water than had been intended; and by sinking so much will displace the additional quantity of water necessary to make up the extra weight, and so, though it swims, will swim too deep. More displacement must therefore be found to meet the deficient weight; the vessel which was intended to swim light will swim deep in the water, unless her weight be diminished by lightening until she return to her former intended depth: what is to be taken care of in the calculation, therefore, is that at whatever depth it has been decided that the ship shall float in the water—or, which is the same thing, at whatever height the upper part is to float above the water—in that position the bulk of the part in the water and the weight of the whole ship and its contents must be so designed as to be exactly equal to the bulk of the water to be displaced by the ship and the weight of the water to be so displaced.

In a ship, however, it is necessary to do more than calculate *one* displacement. There are *two* critically important displacements to be calculated for every vessel.

Displacement when she is lying in the water ready to take in her guns or stores or cargo, or in the lightest state in which she will ever swim—that is, with a clean-swept hold; this is called, technically, "*light displacement.*" The other is "*load displacement,*" which is calculated for the heaviest weight she will ever carry, and the deepest draft of water to which she will ever sink under a load. These are the two important *drafts* or depths of the ship in the water.

To calculate these the constructor must first ascertain the exact weight of the hull of the ship. He must include in the weight of the hull all the essential parts attached to and connected with that hull. He must add to that the full equipment necessary to fit her for sea-going use; but he must not include those stores (water, provisions, coals, etc.) which are to be consumed in actual service. This weight of hull and equipment for service constitute the data on which to construct the light displacement of the ship.

The load displacement is next to be calculated. The data for this consists—first, of the light displacement; and secondly, in addition to this, of all the stores, provisions, water, coals and consumable commodities to be used on the particular voyage or service intended, together with the cargo, freight, etc., of every kind which has to come on board.

To the "light displacement" corresponds what is called "*the light draft*" or light line of the ship. To the load displacement, "*the load draft*" or load water-line. There is also the "*light trim*" and "*the load trim*"—trim meaning difference of draft, or rather the difference between the depth of the after part of the ship under water and that of the fore part.* It is usual to give a ship such trim that the draft of water abaft is somewhat greater than the draft forward, and in this case she is said to be *trimmed by the stern.* If it were the contrary, she would be said to be *trimmed by the head.* This is what is meant when we say a ship is trimmed 2 feet by the head, or 2 feet by the stern; this difference of 2 feet being technically called the trim. When a vessel trims neither by the head nor stern, but draws the same water forward and aft, she is said to be "*on an even keel;*" and it is usual to take a middle draft, halfway between the two, and to call it "*the mean draft,*" so that a ship which is trimmed to 21 feet by the stern and 19 feet at the bow, is said to have "a mean draft" of 20 feet. In this case it is common also to call this 20 feet "the draft of the ship," and to call the greatest draft of water (21 feet) "*the extreme draft;*" but in the calculation of displacement it is general to use the "mean draft."

The elements to be considered in calculating displacement are as follows:

1. Dead weight when light.
2. Dead weight when laden.
3. Light draft of water.
4. Light trim.
5. Load draft of water.
6. Load trim.

These elements being settled, the naval architect may calculate exactly the displacement of a ship of any given form of which he may possess a design—*first,* for her light draft of water; *second,* for her load draft.

First. For her light draft he marks off on the drawing of the ship the exact part of the body of the vessel which will be under water when she floats light. He calls this "*the immersed body*" of the vessel (light). He then measures exactly and calculates geometrically the bulk of this immersed body; this bulk will be expressed in

* Commonly called "*drag.*"

so many cubic feet—say 18,000. He next takes the weight given for the ship and her equipment when light—say 500 tons.

Now he knows that a ship will float at a given draft of water when the quantity of water she displaces is of exactly the same weight as herself, and in this case the weight is given as 500 tons. The question, therefore, is, Whether the volume of water—namely, 18,000 feet —which is the bulk of the immersed body (and which is therefore the quantity of water displaced), will weigh more or less than 500 tons?

Now, it will be found that the bulk of 500 tons of water is just 18,000 cubic feet, and the displacement of the ship, as measured, is also 18,000 cubic feet; this, therefore, is the true light displacement.

Secondly. For her load draft he marks off on the drawing of the ship the exact part of the body of the vessel that will be under water when she is deeply laden. He then measures exactly and calculates geometrically the bulk of that part of the vessel which was formerly out of the water, but which has now been sunk under it by the lading. Suppose this bulk to be 36,000 cubic feet. Thirty-six thousand cubic feet weigh 1000 tons; therefore, 1000 tons is the dead weight of cargo which the ship will carry on the given load water-line.

But the total load displacement of the ship consists, first, of the light displacement of 18,000 cubic feet; second, of the lading displacement of 36,000 cubic feet more; so that the total displacement of the ship when laden is the sum of the two, or 54,000 cubic feet. The immersed body of the ship at the load draft has, therefore, a total displacement of 54,000 cubic feet; and the ship with her cargo floats a total weight of 1500 tons.

Calculating the weight a ship will carry at a given draft of water, is then a mere question of the measurement of the bulk of that part of the ship which will then be under water, and which is called the "immersed body." For every cubic foot of that immersion the weight of a cubic foot of water is allowed, and thence is obtained the number of tons weight the water will support; this is called the "floating power" of the ship, and really represents the buoyant power of the water acting on the outside of the ship. The ship itself has no power to carry anything, or even to float; all it does is to exclude the water and enclose the cargo. The ship is merely passive, the water carrying both ship and cargo.* *Buoyancy* is, therefore, the power of

* An iron ship will best illustrate this.

water to carry a given ship. It is proportioned *exactly* to the bulk of the body of the ship under water, and its force is measured by the weight of the water displaced, and which is called the ship's displacement.

The floating power of a ship has nothing to do with the *shape* of the ship, but is entirely due to its *size* or *bulk*. Practical ship-builders, ignorant of the *laws* of naval architecture, have imagined that they could confer surprising powers of flotation and ability to carry heavy weights, merely by giving certain "*proper*" shapes, imagined by themselves, to the immersed bodies of their ships. This delusion was common at one time, but has now passed away; yet it will take a great deal of thought to understand thoroughly why no possible invention of shape can give to a ship the power of greater or less buoyancy than is measured by the exact weight of water of her displacement. It is herein that the merit of the discovery by Archimedes consists, since the existence at one time of an opposite opinion tends to show that the principle of flotation is by no means self-evident.

TABLE III.

Standards of Displacement.

WEIGHTS.	BULKS.	SIZES.
*1 ton.........	*36 cubic feet fresh water.....	2 × 3 × 6 feet.
†1 "	†35 " sea water.......	2 × 2.5 × 7 "
*62.5 lbs.......	*1 cubic foot fresh water.....	1 × 1 × 1 foot.
†64 "	*1 " sea water.......	1 × 1 × 1 "
‡10 "	1 gallon of fresh water......	6 × 6 × 7.69 inches.
1 lb..........	‡27.648 cub. inch. fresh water	3 × 1 × 9.216 "
1 ounce	1.728 " "	1 × 1 × 1.728 "
0.58 ounce..	1 cubic inch "	1 × 1 × 1 "
2 tons........	72 cubic feet "	6 × 6 × 2 feet.
5 "	180 " "	6 × 6 × 5 "
10 "	360 " "	6 × 6 × 10 "
100 "	3,600 " "	6 × 12 × 50 "
200 "	7,200 " "	6 × 12 × 100 "
1,000 "	36,000 " "	12 × 24 × 125 "
10,000 "	360,000 " "	24 × 50 × 300 "
20,000 "	720,000 " "	24 × 75 × 400 "

* 62.5 pounds = $\frac{1}{35.84}$ tons = $\frac{1}{36}$ tons nearly, and 1 ton = 35.84 ft. *distilled* water.

† 64 lbs. = $\frac{1}{35}$ tons exactly, and 1 ton = 36 cubic ft. salt water.

‡ The *imperial* gallon contains 10 lbs. of distilled water at a temperature of 62.5 Fahrenheit, and also measures 277.274 cubic inches. If ordinary fresh water is taken at a lower temperature (say 40° Fahr.) as the standard, a cubic foot of fresh water will weigh exactly 1000 ounces, or 62.5 lbs. All the figures given above are correct within a very small fraction. In round numbers, 36 cubic feet of fresh water and 35 feet of sea water measure 1 ton. The *standard* gallon of the United States weighs 8.338 pounds, and measures 231 cubic inches.

CHAPTER VII.

BUOYANCY—POWER OF WATER TO FLOAT BODIES HEAVIER THAN ITSELF.

Iron and steel are heavier than water, nevertheless out of them can be formed ships which will not only float well above the surface, but will carry within them weights much heavier than themselves. Iron is nearly eight times heavier than water, and sinks instantly; lead is fourteen times heavier, and gold nineteen. Nevertheless gold and lead may be floated in ships of iron and steel; and structures every portion of which would, if separate, sink to the bottom of the water, can be so combined as to float lightly on the top. The means by which this is accomplished is a dextrous application of the forces of pressure of the water in such a manner that the downward pressure of the weights on a ship shall be counteracted by an equal upward pressure from the water under the ship, and so the vessel be prevented from descending into it more than intended.

But this is not the only use to be made of the pressure of water, since a ship, although supported from below, may roll over by its own weight, or may be overset by the force of the wind or the force of the waves; and so it becomes necessary to call in the aid of the force of the water, not merely to keep the ship from sinking, but to prevent it from being overset. In the first case, the water gives buoyancy only; in the second case, it is said to give *stability* also. In the former case, it gives *vertical* support; in the latter case, it gives *lateral* support. The two great services required of water are, therefore—*first,* buoyancy to support bodies much heavier than itself; *second,* stability to be given to bodies which are unable to keep themselves in an upright position without its aid.

Thus, from an element which is light, movable and unstable is to be drawn support and stability by the art of naval construction. It is plain, therefore, that art and skill can have no sure foundation

except in a complete comprehension of the nature of water and of the laws which govern the application of its force.

The *first* property of water, commonly called its *liquidity*, is its absolute indifference to shape; that is, it presses on all shapes equally. The *second* quality of water is *the absolute proportion of its pressure to depth.* The *third* property of water is *the proportion of its pressure to the extent of the surface on which its presses, altogether regardless of the direction of that surface.* The three elements, therefore, for the calculation of the mechanical force of water are *weight*, *depth* and *extent of surface.*

It is the liquidity of water which takes from it any tendency to assume fixed form in its own masses (as frozen water or ice does), or from exerting any force (as solid bodies do) to keep a shape in which it has been put. As a liquid it will take the exact shape of any vessel into which it is poured, as well as the exact shape of any solid placed in or on it. Therefore, to know how much any vessel of curious shape will hold, fill it with water and then empty its contents into some vessel of known size; the result is the exact capacity of the vessel.

Again, if you wish to know the bulk of anything of complicated form, plunge it into water, forcing the overflow of water into something that you can measure it with. The bulk of the displaced water is exactly what is occupied by the body now in water. This free flowing, easy running and perfect fitting of water seems to imply that it has no force, no resistance to moving, no power of effort. Could it be fancied that water had no weight, it might be fancied also without strength or resistance.

Therefore, as liquidity allows water to be parted hither and thither, and turned into any and every shape indifferently, one must look for the source of its power to sustain, to resist and to act in its next quality—weight, which quality of matter is also indifferent to shape. The weight of a piece of iron, for example, cannot be altered by changing its shape. The weight of a quantity of water is the same whatever the shape of the vessel it may be put into, or whatever shape of outline may be given to it.

The measure of weight in a given quantity of water is as follows:

Quantity of Water.		Weight.
1 cubic inch	250 grains =	.036 lb.
12 " inches	3000 " =	.43 "
28 " "	7000 " =	1. "
1 " foot	1000 ounces =	62.5 "
36 " feet	1 ton.	

These numbers are convenient for the purpose of the naval architect, yet it must be remembered that all water is not precisely alike in weight. The purer waters are represented by the above figures sufficiently well for all practical purposes; but salt water weighs more than river water, and varies in different seas. Some sea water is so heavy that 35 cubic feet will make a ton, instead of 36, and such salt water carries ships better than fresh, in the proportion of 36 to 35.

In calculations of ships for the sea, 35 feet may be conveniently taken as a ton, and 64 lbs. as the weight of a cubic foot.

The nature of the pressure of water is, that it will flow freely into any vessel into which it is allowed to run, and will fit it exactly. But if, in the bottom of the vessel, it find a hole or a weak place, it will rush out there if not stopped by force. If force be applied to the hole or the weak place to prevent the escape of the water, this force is measured exactly by the height of the water above it and by the size of the hole.

The next point in the nature of the pressure of water is, that under the pressure due to its depth the water is indifferent to direction; for if, at the depth of one foot, the pressure downward is .43 lb. on an inch of surface, there is that pressure of .43 lb. on that inch, whether it lie with its face downward or upward, backward or forward, to the right or to the left, or in any degree of obliquity of direction. Pressure proportioned to depth, to extent of surface, but alike for all shapes and for all directions, is characteristic of water pressure. The quantities given as the weights of water enable one to measure exactly its pressure. If the water be a foot deep, and the hole a square inch, the pressure of the water outward is measured (for fresh water) by the weight .43 lb.; at double the depth, .86 lb.; and for every foot of water an equal added weight. To stop it requires just this weight applied the contrary way. The pressure of water trying to get out of a full vessel which confines it is not different in kind or quantity from the pressure of water that surrounds a vessel,

trying to get into it. If an opening be made under water in an empty vessel, like a diving-bell or a ship, the water around it will press into it with just the same force as it would press out of a full vessel, because the water is indifferent to the direction of the pressure.

The pressure of water into a vessel submerged in it being about .43 lb. for each inch, it follows that at the depth of 36 feet the pressure on one inch of the vessel is 15.5 lbs.

Therefore, in a deep ship the pressure is greatest at the bottom, since the water presses against her on every inch of "skin" with a force of .43 lb. for each foot of draft. At 1 foot draft, the water presses inward .43 lb.; at 7 feet, 3 lbs. on the inch; at 28 feet, 12 lbs. on the inch; and at 36 feet, 15.5 lbs. to the inch. This is the measure of the force required to prevent water leaking into a ship through the seams of the sides and bottom, as well as the force that crushes her inward, and requires strength in the hull to resist it.

The power of water to float bodies is given by nothing more than the pressure of water under the vessel which is pushing it upward. To measure the buoyancy is nothing more than to measure the pressure of the water on the whole bottom of the ship upward. Let it be conceived that she has a flat, level bottom and upright sides, and floats 10 feet deep in the water, then the buoyancy and floating power of the ship will be measured by the upward pressure of the water. At 10 feet below the water, this pressure is 625 lbs. upon each foot of skin. Therefore reckoning the number of feet on the bottom to be say 1000, the upward pressure of the water, or buoyancy, will enable her to carry 625,000 lbs.

In this calculation of buoyancy, the upward pressure of the water has been measured by the same rule as if it had been downward pressure, because it has already been shown that it is the characteristic property of water pressure that it is proportionate to depth, and is not affected by direction. It is this universality of the pressure of water, with its indifference to direction, which makes the calculation of buoyancy so simple and easy. This principle of buoyancy and its measurement make it clear how bodies like iron, steel and brass, so much heavier than water, can be made to swim, even although, according to the law of displacement, they weigh much more than the same quantity of water.

The art of making heavy bodies swim consists, then, in this: to

spread them out in a thin layer over so large a quantity of water and at such a depth that the pressure of the water upward shall be greater than the pressure of weight downward.

A cubic foot of iron weighs 448 lbs., and would sink in water instantly. But take that mass and roll it out into a thin plate 8 feet long and 8 feet wide, and turn up its edges all around a foot deep; then the upward pressure of the water on the 36 feet of bottom, at the depth of one foot, will give 62.5 lbs. on each foot, or one ton of 2240 lbs. on the whole piece. The buoyancy, therefore, of the water on this extent of iron is enough not only to float the original 448 lbs. forming the cubic foot, but also to carry a load of 1792 lbs. besides.

This example shows, in a striking manner, how a ship may not only be built of iron, which sinks by itself in water, but may be so built as not merely to carry its own weight of iron, but a burthen in addition four times greater than its own weight.

Such is the buoyancy of water: and therefore to carry any known weight, it is only necessary that the surface of the bottom of the ship be large enough and placed at a sufficient depth below the water to produce an aggregate upward pressure equal to the aggregate weights carried.

TABLE IV.

Pressure on the bottom of a Ship in Sea water.

Depth under water.	Pressure on a square foot.	Pressure on a square inch.	Depth under water.	Pressure on a square foot.	Pressure on a square inch.
feet.	lbs.	lbs.	feet.	lbs.	lbs.
1	64	.44	13	832	5.78
2	128	.89	14	896 = .4 ton	6.22
3	192	1.33	15	960	6.67
4	256	1.78	16	1024	7.11
5	320	2.22	17	1088	7.56
6	384	2.67	18	1152	8.
7	448 = .2 ton	3.11	19	1216	8.44
8	512	3.56	20	1280	8.89
9	576	4.	21	1344 = .6 ton	9.33
10	640	4.44	28	1792 = .8 ton	12.44
11	704	4.89	35	2240 = 1. ton	15.56
12	768	5.33			

CHAPTER VIII.

STABILITY—POWER OF WATER TO MAKE A SHIP STAND UPRIGHT.

THAT the most unstable of elements, water, should be required to confer stability or give uprightness to heavy bodies raised to a great height above its surface, would appear to be an unreasonable expectation, were it not accomplished every day.

If it is merely imagined that the bottom of a ship is made the heaviest part and the top the lightest, it would seem naturally to follow, as a first impression, that the bottom, being the heaviest, would stay at the bottom, and the top, being the lightest, would stay at the top. This disposition of weight is not what always or often, in fact, takes place. A Mississippi or North river steamboat is 30 feet high out of the water, and but 3 to 6 feet, or so, deep in it. The heavy weights of its machinery are generally high out of the water; its boilers are entirely above the water, reaching in some cases above the hurricane deck. Its cargo is also carried above the water, and its bottom, if not quite empty, is merely occupied by sleeping apartments. Such vessels, if supported on pivots fixed at the water-line, would certainly tumble over, bottom up, since they are certainly top-heavy, and pivoted *on land* would upset. By some power, nevertheless, *in the water* they are kept upright, and made to form huge floating castles, their chief weights high in the air.

It is, therefore, necessary to examine, understand and measure by what power water gives stability and uprightness to a large, top-heavy, out-of-water structure.

It might be imagined, at first sight, that the upward pressure of the water on the bottom should help to give uprightness to the structure it upholds from below. But this idea will not stand

examination; since to push the bottom of a vessel upward may only be another method of trying to upset it. What is wanted is to keep the top up and the bottom down.

How, out of these contradictory elements, to elicit stability is neither an obvious nor an easy investigation, for it is certain that the upward pressure of the water on the bottom of a ship, instead of being a cause of stability, is a powerful agent of instability, and that the greater it is in quantity and the more effectual in power the more it tends to upset the floating body.

Nevertheless, a perfect understanding of the way in which the power of water contributes to stability in a top-heavy, out-of-water structure will give one a profound appreciation of this remarkable quality of water. The way in which this unstable element gives stability to a top-heavy structure, as it heels over, is by continually transferring its action to the side to which the vessel is about to fall, where, by continually giving a stronger push upward on the falling side, it counterbalances the falling weight, and thus keeps the vessel upright.

A top-heavy ship is technically called "*crank*"—"a drunken ship"—and it really seems so; but by art, the force of water is made to pass from side to side, faster and farther than the ship heels, and therefore, though she may heel over, she cannot capsize, for the water puts its strong pressure under the falling "*shoulder*" of the ship, and gives it a powerful lift. The way in which this "shoulder" is formed, the leverage with which the water acts, and the powerful lift which it gives at the right time and in the right way, is something which it requires much thought to conceive, skill to direct and craft to apply with success. This portion of the ship is therefore called the "*shoulder*," to distinguish it from the bottom or "*bilge*" of the ship.

It is the tendency of the bottom or bilge of the ship to be pushed upward by the water, and the pressure is so great upward as to tend not only to keep it up, but to push it too much up, and thus upset the vessel. One way of counteracting this would be to put heavy weights of lead or iron on the bottom of the ship, so as to keep it always, in all circumstances, bottom down. But to put on the bottom of a ship useless weight is not merely a confession of great want of skill, but is a serious sacrifice of the usefulness of the ship.

It was the practice of a former day to make up for want of sta-

bility by great quantities of ballast; but the naval architect of the present day knows how to give sufficient "shoulder" to the ship so as to make use of the fluidity of the water as a substitute for the "*dead weight*" of ballast; and its just application is a test of his skill.

By the "shoulder," therefore, is meant that part of the side which is just about the water-line, which is sometimes a little out of and sometimes a little under the water as the ship reels about. It is frequently called, for that reason, the part of the ship "*between wind and water;*" but it will be quite accurately defined if it is said that the "shoulder" of a ship is that part which, being under the water when the ship heels over one way, is then left bare, out of the water, when she heels as far over the other way.

Take, for example, a ship that has been standing upright, and has first leaned over on one side until 2 feet of her *skin* are put into the water, and then leans over just as much on the other side till 2 feet more of her skin are out of water,—those 4 feet of skin on each side which lie between these extreme positions are "the shoulders," on which she depends for power to sustain top weight.

If from the body of the ship the two "shoulders" are taken, the remainder of the bottom, which never leaves the water, may be defined as the "*under-water body*" of the ship, and this under-water body is the part tending to upset her. The life of the ship is, therefore, a balanced effort, the under-water body continually tending to upset her, and the two "shoulders," turn and turn about, trying to keep her upright. The one is the "*upsetting*" part, the other the "*righting*" part of the ship. The effect of each of these contrary elements has to be measured—*first*, by the quantity of each element; *second*, by the more or less effectual manner in which it is applied. To make the upsetting body the largest in quantity for the purpose of carrying useful loads, yet so to contrive it as to give it the least power for harm—to make the "shoulders" the smallest, yet so contrived as to have the most power for good,—that is the consummation of the art of the architect.

In every ship it will be a question depending on her peculiar structure how much of this righting power has been given to her; in other words, how much top weight she can carry, and how high out of the water she can carry it, without upsetting. The simplest way

of putting it is, perhaps, to ask at what height the whole weight of the ship herself and all she carries might be kept without overpowering the stability, overworking the "shoulders," and thus upsetting the ship.

This height is, therefore, a chief point to be calculated and known, and may be called the "upsetting point." It is, however, called the "meta-centre;" and if this be taken to mean the point beyond which you cannot go in raising the weights, it is a proper word enough. The limiting height of top weight is, therefore, the proper meaning of what is called the meta-centre, and the measure of this is manifestly one of the most important things to be known about a ship, for on it most of her good qualities depend.*

* The point M in figs. 2 and 3 is the meta-centre for the given "angle of inclination." It is evident that unless this point be above the *centre of gravity of the ship*, the vessel will upset.

CHAPTER IX.

STABILITY—POWERS OF "SHOULDER" AND UNDER-WATER BODY.

To understand the functions of the "shoulder" of the ship and those of the bottom, and the tendency of both to affect the stability, it will not be necessary to consider any but the simplest form which can float. For that purpose, suppose a square box of say 36 feet wide, 27 feet high, and of indefinite length, to be sunk by a weight 18 feet deep in the water—each foot of length of a box of these dimensions will carry a ton weight for every foot of its depth in fresh water; therefore, 18 feet of depth carries a weight of 18 tons. And supposing the box itself to weigh 6 tons per foot, the vessel would carry, beside its own weight, a weight of 12 tons. Draw such a box, and across it the line of the surface of the water, which call the "*water-line.*" Let the weight be represented in square form on top of it. (Fig. 1.)

This box truly represents a ship, the weight truly representing a heavy deck-load proposed to be carried by the ship. It may represent the weight of a man-of-war's battery, or the weight of an iron-cased battery, an iron-clad's turret, or any other top load.

The question is—the ability or inability of that ship to carry that weight at that height out of the water. For this purpose, suppose it to lean over on either side, and then examine whether it tends to return to the upright position and stand up, or to overset and drop the weight into the sea. Draw the ship, therefore, in these two positions. (Figs. 2, 3.) When this is done, it will be seen that there is a part of the ship which is never out of water, but keeps always under the water-line. This is the under-water body, or the upsetting part of the ship.

This under-water body is bounded by, first of all, the bottom of

the ship; secondly, by the bilges, or corners of the bottom; and thirdly, by a water-line of the ship in each of its two opposite positions. It is, therefore, pointed at the top where it forms an equal-sided triangle, the apex of which is in the water-line. Two flat surfaces, therefore, form the top of this under-water body, while the rest of it forms the bilges and bottom, or under-water skin of the ship. The part shaded (fig. 4) is that part which tends to upset the ship, and the nature of this upsetting force, produced by the under-water body, must be examined.

To this end observe that it is a symmetrical body, the right and left sides being of the same size, of the same shape, and in the original upright position of the body exactly balancing on both sides. Its whole effect, then, may be assumed as concentrated in a point in its middle line. This point call B, or the centre of effort of the under-water body.*

The buoyancy or upward pressure of this under-water body will take place directly upward in the line B*b*, and it will be seen that this is quite on one side of the centre of the vessel. It is next to be noticed, in figs. 2 and 3, that the centre of the weight W is on the opposite side of the upright line. When the ship careens over to the right, the weight also inclines to the right and downward. When the ship careens over to the left, the weight also inclines to the left and downward. The direction of its effect is marked by the downward line W*w*.

Therefore, when the ship is lowered on the right side, the effect of the weight from above is to press it downward on that side, while at the same moment the effect of the under-water body is equally bad in raising the opposite side out of the water. The ship is beset by two opposite forces, which, nevertheless, conspire in their bad effect. One sinks the right in the water, while the other lifts the left out of the water, so that with opposite means both tend to overset the ship. It is thus seen why the under-water body is the upsetting part of the ship. The larger it is, and the greater its power to carry weight, the more it will tend to overturn the weight it carries.

Some counteracting power must, therefore, be looked to, not merely to neutralize the overturning effect of the top weight and the upsetting force of the under-water body, but to do more than

* Of course this point represents the resultant of an infinite number of pressures.

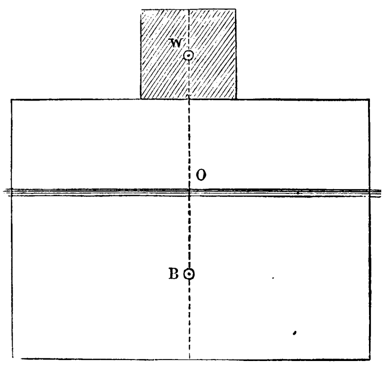

FIG. 1.

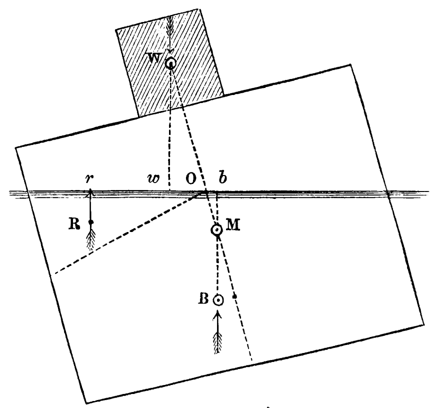

FIG. 2.

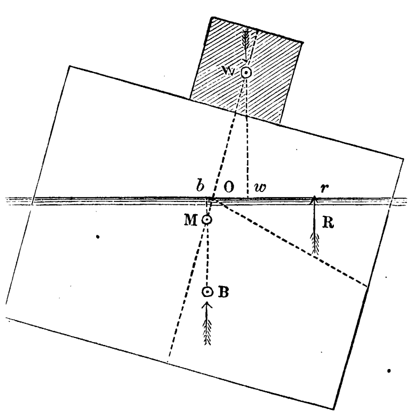

FIG. 3.

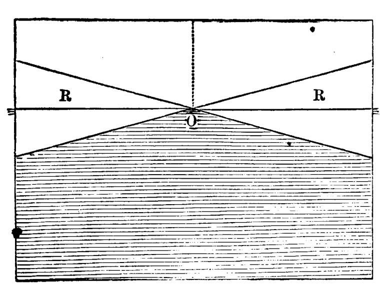

FIG. 4.

neutralize them—to give a balance of righting force which shall constitute the stability of the vessel; in other words, the power to right herself after she has been forced over.

This righting force is found in the "shoulders," which lie between wind and water, and are continually going in and out of the water on one side or on the other. When she leans over to the right, the whole of the right "shoulder" is immersed; and the same may be said of the left "shoulder," each consisting of a wedge-formed body, with its point at the middle, and the base or heel of the wedge on the outside of the ship, the whole of the base or heel rising out of the water, and falling into it again as the ship careens. One-half the angle of this wedge is called "*the angle of heel*" or "*the angle of inclination*," and is taken as the measure of the roll or careen of the ship. A ship, for example, is said to roll or careen 15° when the angle of this wedge is an angle of 30°. It is convenient generally to speak of some fixed angle for this purpose, and 28° may therefore be assumed. For ships of war it has been common to use 15°, as it is desirable for the sake of the guns that the ship should *not* roll or careen *more* than this;* but for merchant ships, under a press of sail, there is no harm in their careening 14° in and 14° out of water, a total of 28°. These wedges or "shoulders" are sometimes called "*the wings*," sometimes "*the solids of immersion and emersion.*"

To examine the effect of each "shoulder," when it has been forced under water, to rise again and raise the top weight with it, one must consider the *amount* of its effort, the *place* where it may be reckoned as concentrated, and the *direction* of its effort. The quantity of its effort is measured by its buoyant power, or the number of cubic feet of water it displaces. Its bulk in water, therefore, gives a measure of its buoyant or upward force. The place in which this buoyant effort takes effect is about two-thirds ($\frac{2}{3}$) outward from the point O of the wedge (fig. 4). The effect it produces may be assumed then as concentrated in R, and the buoyant effect, being directly upward, tends to upright the vessel on the side which has been depressed under water.

But it should be observed that that side of the ship on which the "shoulder" lies under water is also that side on which the top

* With the exception of our monitors, few of our screw men-of-war can claim even this.

weight tends to descend and overset; and it is therefore obvious that the tendency of the "shoulder" is to help the descending weight to rise again, and therefore to right the ship.

But the vital question is, Whether the "shoulder" has *power* enough to do so? In order to be effectual, it will not be sufficient that it should be capable of supporting the top weight merely. It has also to counteract the upsetting tendency on the opposite side produced by the under-water body.

It must not escape notice that the under-water body is always on the contrary side from the "shoulder," always tending to upset the ship on that side from below, so that unless the "shoulder" be more powerful and act more energetically than the under-water body, the ship will infallibly upset. The "shoulder," therefore, has these two tasks at once: It must be strong enough to neutralize the upsetting force of the under body at the same time that it sustains and counteracts the oversetting force of the top weight, and the surplus power beyond these two will right the ship.

It is this surplus power, beyond the two effects counteracted, which gives stability, its measure being called "*the measure of the stability of the ship*," and the art of the constructor is to make it always just as much as is wanted for this purpose, and *no more*, for more is of itself an evil, and defeats other good points.*

To measure the upsetting force of the under-water body, its volume is measured, after which its power is found by taking the weight of an equal quantity of water. Then assume that power as applied at its centre of action, commonly called "centre of gravity"(B). Draw a line directly upward through this point, and call that "the line of action of the upsetting force." Mark the place (*b*) where this line cuts the water. It is on the water-line that the comparison between the forces causing stability can be most directly seen; hence it may be called "the line of comparison."

To measure the righting force of the "shoulder," in like manner measure its volume, then find its power by taking the weight of an equal quantity of water. Reckon this power as applied at its centre of action or centre of gravity (R), and draw a line directly upward through this point, calling it the "line of action of the righting

* Too much stability is almost as great an evil as too little. (See Art. 11th, p. 18.)

force." Mark the place (r) where this line cuts the water, and here its action may be compared with that of the other two forces.

The third force has been already measured; it is the top weight placed on the vessel, and it is 12 tons for each foot of length. To compare this with the others, let fall through its centre of gravity (W) its line of action, which cuts the water at some place intermediate between the other two. Mark this place (w). The water-line now shows the three points of comparison desired.

Of the three—first, compare the upsetting and righting force of the body and "shoulders," which are on opposite sides of the middle of the ship and counteract each other. In the case under consideration, one, the upsetting force, is much larger in quantity than the other, the righting force—larger in the proportion of 3 to 1; but the smaller force acts more advantageously than the greater, so much so as to overpower it, because its centre of action (r) is four times farther from the centre of the ship on one side than the point of action (b) of the other. The combined result, therefore, is in favor of the righting force, and the ship has stability and will right itself. If the other force had preponderated, it would have had instability and have overset, even without a deck load. The question now remains: How much stability has it? In other words, how much top weight will the ship carry, and how high?

To find this, multiply the volume of the under body by the distance (Ob) of its line of action from the centre, subtract it from the righting force multiplied by the distance of its line of action (Or) from the centre; the balance, in figures, shows the balancing quantity of force the "shoulder" is able to carry. This may amount to a weight of 12 tons, multiplied by the distance of the line of action (Ow) of the top weight from the centre of the line of comparison. If this be so, the vessel has stability enough not to be overset; if, on the contrary, the surplus is less than this, the vessel will be overset. This surplus sustaining power, however, is the measure of stability. But in this calculation all consideration of the effect of the weight of the ship itself, either in oversetting or in righting, has been omitted. It may happen, and does happen in practice, that the weight of the ship alone, without a deck load, is enough to upset her.* In such

* It has occurred in practice that vessels upon being launched have immediately turned bottom up.

case the weight of the deck load must be treated as the whole weight of the ship, the point of action of this weight being taken in the centre of action of the sum of all the weights of all the parts of the ship and her equipment. In this view of the case, after substituting in the calculation the total weight of the ship, as well as the weights on it, instead of the deck load, we must examine the height at which the whole of these could be carried without upsetting.

This height is taken as a convenient way of estimating the surplus righting power of the "shoulders" of the ship; because in comparing different ships one may, without reference to their weights or displacements, compare their righting powers or stability by the height above the water at which they have power to carry their own weights. For example, a ship which has power to carry her own weight 6 feet above the water, and another which has power to carry hers 3 feet out of the water, may be said to have relative stabilities of 2 to 1; but if the magnitude of the ships also be considered, and one is double the bulk of the other, and has power to carry its weight twice as high, the absolute stability of the one may be four times that of the other, although their relative stabilities, reckoned by height alone, are as 2 to 1. The upsetting power of the bottom of a ship and the righting power of the "shoulders" are, therefore, the two rival forces which continually oppose one another.

These two forces depend entirely for their quantity, their proportion and the manner of their action upon the forethought, knowledge and skill of the *designer* of the ship.

The proper balance of these forces in the design makes the ship a good or bad carrier of top weight, and the height at which it can carry all its weights is a point of the greatest value in every ship, and in men-of-war especially. If a considerable mistake be originally made, it is scarcely possible to correct it by anything short of rebuilding the ship.

CHAPTER X.

ON THE PROPORTIONS WHICH MAKE A STABLE OR UNSTABLE SHIP.

In framing the design of a ship few things are of greater importance to be clearly seen, and unceasingly kept in mind, than the effect of the bottom to diminish, and the "shoulder" to increase, power to carry top weight. In order to give a ship this good and indispensable power, it is important that the naval architect should not for a moment lose sight of the contrary nature and tendency of these two forces, since it is from the omission of, or inadequate consideration given to, these two effects that crank, unstable and unseaworthy ships have so often been built.

Crankness was a general fault of ships built in the early part of this century, and means two things: inability to stand upright, and facility of being upset by top weight. The cause of crankness is often supposed to be shallow draft of water, which would be cured by deeper immersion. This is a radical error; there is no more common source of crank ships than this general impression. The contrary is the truth.

Take a square ship, like a box, filled with a light material, so as to sink no deeper than *one-fourth* part of its breadth, it will stand upright well; fill the same with heavier materials, so as to sink it to *double* that depth in the water, it will immediately turn bottom up. This is a very common proportion of draft to breadth, especially in old ships, and is quite sufficient to make a bad ship. As a general rule, then, ships with a deep and large bottom and narrow "shoulders," or with a straight, upright side and flat bottom and sharp bilges, will be crank.

In most cases ships that are crank may be cured by altering them so as to increase the breadth of their "shoulder" without altering

their bottom.* They may also be cured by lengthening them, so as to make them, with a given load, draw less water. Both plans have been tried with success.

Table V. at the end of this chapter is given to show the limits of the power of a square-built, wall-sided ship to stand upright under heavy and high loads. To each breadth there is a given height, up to which she can carry top weight, and the table shows with what proportion of depth in the water to breadth she can or cannot carry her weights above water; thus the table shows that such a vessel, 36 feet broad and 18 feet deep in the water, cannot carry her weights if their common centre lie above the water, and that she would require to be 48 feet broad to carry them just 20 inches above the water.

In this table the figure 0 shows that if the whole weight carried were no higher than the surface of the water, the ship would, nevertheless, be incapable of standing upright, and would either list over or upset. The figures show how high the centre of gravity of all the weights carried, including both the material of the vessel itself and the burden with which she is laden, might be raised above the waterline without instability or danger of upset.

The value of this table is manifold; it shows how the extremely shallow, flat vessels of the Mississippi and other rivers are able to stand up under their very heavy top loads and carry enormous floating hotels three and four stories high above the surface of the water. It is their small proportion of depth in the water, combined with their great breadth, which does it.† It is this proportion which enables them to carry not only their light cabins, but also their heavy engines, boilers, fuel and deck loads above the water.

It shows the proportions for floating-docks, which have to take ships of great weight, raise them high and dry above the water, and carry them steadily there. It also shows how high the centre of gravity of a ship may be which a floating-dock of given proportions can carry, taking into account, also, the weight of the floating-dock itself. It shows how the shallow floating platforms of such con-

* This is sometimes done by means of "sponsons." For the same reason a side-wheel steamer is more stable than a screw ship. This was effectually proved in the cases of the "Saranac" and "San Jacinto," both of the same model, the guards of the former increasing her stability.

† Refer to table of American river steamers, and this will be seen at a glance.

trivances as Clark's hydraulic docks are able to sustain ships under repair by using the right proportion of depth to breadth for a ship which has her centre of gravity at a certain height above the water.

This table enables one to see, also, how the square-built, wall-sided, deep-bottomed ships, so often built by uninformed or careless shipwrights, turn out unstable and unseaworthy.

In using this table to judge of a ship or design, it must not be forgotten that the case assumed is that of a *box-formed* or *wall-sided* vessel, nearly *rectangular* in shape; but it is nearly true, also, of a vessel slightly rounded off at the corners, and will be pretty exact for many large, capacious ships. It must be carefully borne in mind that the table shows the extreme or upsetting heights to which the centre of weight must *not* be raised. The weights of a well-trimmed ship, intended to carry sail well, should be kept so that the *centre of gravity* may be several feet under the limiting height.

It should be further noticed that the *length* of the vessel is not given in the table. The *breadth* and *depth* being given, the length has *no* effect on the height at which the whole load can be carried. But length has everything to do with the *quantity of weight* which that ship will carry at the *height* in the table. Thus, a ship of 36 feet beam carries one ton for every foot deep; and for every foot in length, as many tons as there are feet of her depth in the water; therefore it is to be remembered that the weights carried at these heights are limited by the total displacement tonnage of the floating body. With these explanations this table is a safe guide for the judgment in regard to rectangular, box-shaped or wall-sided, square-bilged vessels.

TABLE V.

Power to Carry Top Weight.

Heights out of water up to which loads can be carried by vessels of square form and of different proportions of breadth of shoulder to depth of draft.

Draft.		Breadths. (Feet.)													
Feet.		12	18	24	30	36	42	48	54	60	66	72	78	84	90
...	Limiting heights of load in feet and inches.	0	......	......	......	......	......	......	......	......	......	......	......	......	......
6		0	1.6	5.0	9.6	15.0	21.6	29.0	37.6	47.0	57.6	69.0	81.6	95.0	100.6
12		0	0	0	0.3	3.0	6.3	10.0	14.3	19.0	24.3	30.0	36.3	43.0	50.3
18		0	0	0	0	0	0	1.8	4.6	7.8	11.2	15.0	19.2	23.8	28.6
24		0	0	0	0	0	0	0	0	0.6	3.1.5	6.0	9.1.5	12.6	16.1.5
30		0	0	0	0	0	0	0	0	0	0	0	1.8.4	4.7.2	7.6
36		0	0	0	0	0	0	0	0	0	0	0	0	0	0.9

Proportion of Breadth and Draft at which such vessels will upset if they carry Top Weight.

Breadth.	Draft.	Breadth.	Draft.	Breadth.	Draft.
Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
12	4.8990	54	22.0455	14.697	6
18	7.3485	60	24.4950	29.394	12
24	9.7980	66	26.9445	44.091	18
30	12.2475	72	29.3940	58.788	24
36	14.6970	78	31.8435	73.485	30
42	17.1465	84	34.2930	88.182	36
48	19.5960	90	36.7425	102.879	42

CHAPTER XI.

THE METHOD OF MEASURING STABILITY.

1. The first method is to determine how much top weight will careen the ship to a given large angle—say 14° out of the perpendicular, or in war vessels 7°—in order to compare the stability of different ships with one another at this angle.

2. The second method is to find the extremely small degree of careening which will be produced by an extremely small top weight.

By this investigation is discovered a curious quality belonging to crank ships—namely, that although a very small top weight may make them lean over a little, they may, nevertheless, offer great resistance to a great weight tending to incline them much. It is common to speak of such ships as being "*tender*," rather than crank.

The following are the successive steps (figs. 2 and 3):

1st. Measure the bulk of the under-water body, the ship being inclined on alternate sides to the given angle.

2d. Measure the buoyant force of that bulk, taking 36 cubic feet of bulk for each ton of buoyancy.

3d. Find the place of the centre of effort (B) at which this force acts, which is the point commonly called the *centre of gravity of the under-water body.** Next, through the point thus found draw an upright line (B*b*) cutting the water-line at some distance from its middle. Then measure this distance (O*b*) from the middle line of the ship.

4th. The line (O*b*) just measured is called "*the effectual distance of the upsetting force,*" and being multiplied by the number of tons already found as the measure of that force, the product is called "*the momentum of the upsetting body.*" This momentum is taken as the measure of the upsetting force.

* Or centre of buoyancy.

5th. Measure the bulk of the righting body, or "*shoulder*" under water, when the ship is inclined at the given angle.

6th. Measure the buoyant force of the bulk of the "shoulder," taking 36 cubic feet for each ton of buoyancy.

7th. Find the place of the centre of effort in the "shoulder" (R) at which this force acts, which is the point commonly called *the centre of gravity*, and is nearly two-thirds the breadth of the "shoulder" from the centre of the ship, or one-third from the outside.

Next, through the point (R) thus found draw an upright line (R*r*), cutting the water-line at a point (*r*); of which measure the distance from the middle line of the ship (O*r*).

8th. The line (O*r*) just measured call the "*effectual distance of the uprighting force*," and multiply it by the number of tons already found as the measure of that force; this product call "*the momentum of the uprighting force*," and take it as a measure of the uprighting force.

9th. Next subtract the smaller of these two *momenta* from the greater. If the upsetting force be the greater, the ship will overset in that position, unless some heavy weight be placed on the bottom, or some equivalent force be applied to prevent its oversetting, and such a force will, in order to be effectual, require to have a *momentum* at least equal to the difference.

10th. But if, on the contrary, the uprighting force be the greater, the ship in that position tends to upright itself, and can carry increased top weight, until this increased momentum becomes equal to the *surplus* righting momentum.

It is this surplus momentum, either way, that is taken to measure the stability or instability of the ship.

11th. If the surplus righting momentum be *divided* by the entire weight of the ship, the distance will be found to which this whole weight might be removed to one side without upsetting. This distance is reckoned as another measure of stability. If, now, this last measure be divided by the sine of the angle of inclination, the height will be obtained to which the whole weight of the ship might be raised without upsetting it; and this is a third measure of the stability of the ship, and is called the measure in height of stability of form.

It may be found geometrically by taking the point B, and through

it erecting a perpendicular to the water-line, which will cut the upright middle of the ship at this height.

Thus measures of stability are obtained in three forms:

1st. Power to carry a given weight at a given distance out of the middle line.

2d. Power to resist a given heeling force.

3d. Power to carry the whole weight at a certain height above the water.

The second method of calculating the stability of a vessel is to calculate all the quantities given above, for some extremely minute angle of deviation (say 41″) from the vertical position. This may be said to measure the resistance of the vessel to deviation from the vertical, whereas the former method measures her tendency to return to the vertical after having been compelled to make a great deviation from it.

ELEMENTS OF STABILITY.*

Breadth.—The stability of a vessel increases or diminishes enormously with its variation, whether the displacement remain constant, or, the draft remaining constant, the displacement vary with the breadth. In the latter case the height of the meta-centre varies as the *square* of the breadth.

Displacement.—If the breadth remain constant, the stability increases as the displacement decreases. And since in that case the centre of displacement rises, the height above the water-line to which the vessel's load may be carried receives a further increment.

Draft.—Assuming both the breadth and displacement to remain constant, the increase or diminution of draft lowers or raises the centre of displacement, and with it the meta-centre. It does not otherwise effect the instantaneous stability.

Stowage of Lading or Ballast.—The meta-centre indicates the height to which the centre of weight of the vessel may be brought

* There are two kinds of stability, viz.: *Statical* and *Dynamical.* STATICAL STABILITY *is the moment of* FORCE *(or effort) by which a floating body endeavors to regain its upright or vertical position after having been deflected from that position.* DYNAMICAL STABILITY *is the amount of* WORK (*i. e.*, weight of the body in lbs., avoirdupois, multiplied by the vertical height in feet of the sum or differences of displacements of the centres of gravity of the body and of the water it displaces) *done on any body, in order to deflect it through any angle from its upright position.*

without upsetting; and the amount of stability for very small inclinations is measured by the distance between the meta-centre and the centre of weight. The stowage, therefore, effects the instantaneous stability in so far as it raises or lowers the centre of weight, and not further or otherwise. As the meta-centre fixes an absolute maximum, which being reached the vessel has no stability whatever, the weights must, in practice, be kept considerably below it, as the vessel must have reasonable stability.

Curve bounding Plane of Flotation or Form of Water-line.—This element of variation may be considered apart from all others, and even independently of the proportion between length and breadth. *Cæteris paribus*, fine lines may reduce the stability, measured by the height of the meta-centre above the centre of displacement, to one-half what it is in the *rectangular box.* (Fig. 5.)

Length and Lateral Stability.—This element may be always disregarded, except in the mere calculation of actual weights, provided the same breadths and depths at proportionate lengths are maintained.

Weight.—This element is merely a factor, and is of no other account in the investigation of stability.

A vessel with nothing movable in her has her stability completely determined by the moments on the water-line of the three following forces, only two of which are independent:

1st. Her weight.

2d. The upward pressure due to her displacement.

3d. The force required to keep these in equilibrium.

Distinction between Heeling and being Listed.—A vessel is said to *heel* when she is pushed over by an extraneous force, on the removal of which she would alter her inclination.

She is said to be *listed* when she has found equilibrium in any position other than upright, whether owing to an unsymmetric distribution of her weight or to any peculiarity of form. A *list*, therefore, implies equilibrium (though unsymmetric); *heeling* excludes equilibrium.

As applied to a vessel *heeling*, the meta-centre has no meaning, except to indicate how an alteration of the weights might be made to give equilibrium. As applied to a *listed* vessel, it has the same import as to a vessel floating upright. In both these cases it affords

practical means of comparing many different forms, especially where the variation to be considered is in the water-line.

As a rule, when two floating bodies are homogeneous and homologous, and their breadths B and b, their stabilities are to each other as B^4 to b^4. If two homogeneous bodies have homologous transverse sections, but not homologous longitudinal sections, and their lengths are L and l, and breadths B and b, their stabilities are to each other as $L \times B^3$ to $l \times b^3$. A *rough* comparison between two ships may therefore be made by comparing the products of their lengths and cubes of their breadths.

Fig. 5 is 36 feet in breadth and 27 feet in depth—scale, ⅛th inch to 1 foot. After inclining this form to the taken degree, and after having calculated the piece OO′ as mentioned in the table, another line is drawn below the upright water-line on the side of the immersed part, going through O′, making an angle, φ, with the upright water-line. Through this line the whole immersed body is divided into two parts—the "upsetting" part and the "righting" part.

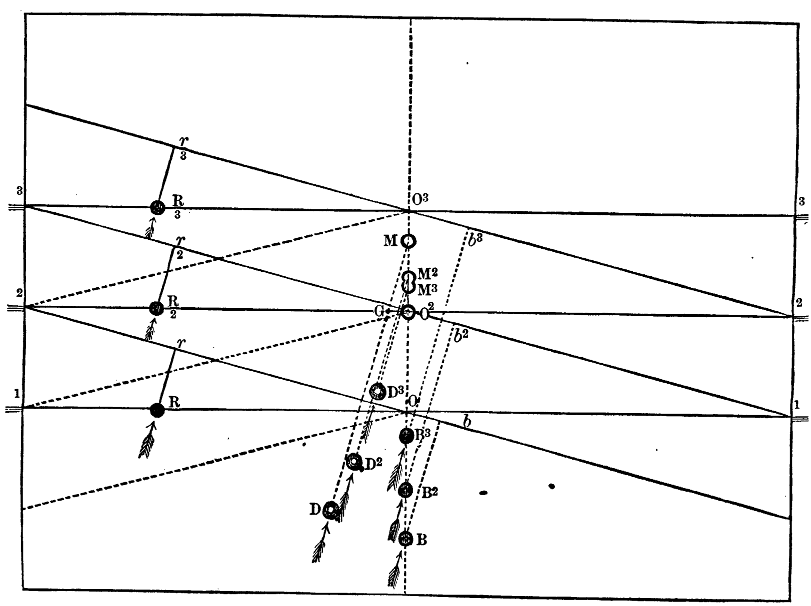

FIG. 5.

TABLE VI.—(*Calculations applied to Fig.* 5.)*

Reference No.	Angle of inclination, o =	14° 2′.			41″, or Index.		
	Draft of water, d =	Feet. 9	Feet. 13.5	Feet. 18	Feet. 9	Feet. 13.5	Feet. 18
1	Volume of displacement in the upright position, D =	324.	486.	648.	324.	486.	648.
2	Volume of displacement in fractions of parallelogram, $b \times d$	1.	1.	1.	1.	1.	1.
3	Centre of buoyancy below water-line, Do =	4.5	6.75	9.	4.5	6.75	9.
4	Centre of gravity of vessel below water-line	4.5	0	—4.5	4.5	0	—4.5
5	Volume of immersed part	40.5	40.5	40.5			
6	Volume of emersed part	40.5	40.5	40.5			
7	Difference	0	0	0			
8	Height to which the vessel has been raised to make inclined displacement equal to upright displacement = $00' = \frac{\text{Diff.}}{ob \cos \varphi}$	0	0	0			
9	Volume of upsetting part	243.	405.	567.	323.93	405.	647.93
10	Volume of righting part	81.	81.	81.	0.0648	0.0648	0.0648
11	Centre of gravity of upsetting part below O′, Bo' =	5.5	7.8	10.07	4.5	6.75	9.
12	Centre of gravity of righting part from O′, Ro' =	12.	12.	12.	12.	12.	12.
13	Centre of gravity of overturning part above O′, Go' =	4.5	0	—4.5	4.5	0	—4.5
14	Leverage of upsetting part, or bo' = Bo' × sine φ =	1.33	1.89	2.44	0.0009	0.0013	0.0018
15	Leverage of righting part, or ro' = Ro' × cos θ =	11.64	11.64	11.64	12.	12.	12.
16	Leverage of overturning part, or go' = Go' × sine φ =	1.09	0	—1.09	0.0009	0	0.0009
17	Effects of upsetting force or upsetting moment, B × bo'	323.19	765.45	1383.48	0.2915	0.5265	1.1662
18	Effects of righting force or righting moment, R × ro'	942.84	942.84	942.84	0.7776	0.7776	0.7776
19	Balance in favor of righting moment, or moment of stability of form	619.65	177.39	—440.64	0.4861	0.2511	—0.3886
20	Moment of stability divided by D, or measure of stability of form	1.91	0.36	—0.68	0.0015	0.0005	—0.0006
21	Limiting height of the centre of gravity of vessel above water, or height of meta-centre above water-line, or MO′	7.88	1.51	—2.8	7.5	2.5	—3.
22	Measure of stability, with weight	0.82	0.36	0.41	0.0006	0.0005	0.0006
23	Moment of stability, with weight	266.49	177.39	265.68	0.1944	0.2511	0.1944
24	Limit to which centre of gravity of vessel may rise from its original position, or height of meta-centre above centre of gravity of vessel	3.38	1.51	1.7	3.	2.5	1.5
25	Distance of meta-centre above centre of displacement (or buoyancy)	12.39	8.25	6.2	12.	9.25	6.
26	Interval between the meta-centre and centre of displacement, or $\frac{b^3}{12 \times D}$	....	....	....	12.	8.	6.

* This table is merely inserted to show the method adopted by Scott Russell in calculating "Stability." For a full discussion of the subject refer to his work.

CHAPTER XII.

STABILITY—POWERS AND PROPERTIES OF THE "SHOULDERS."

THE sum and substance of what is known of the nature of stability is that the "shoulders" *alone* give to the ship righting or uprighting power, and that no other part of the ship can be so formed as to increase the righting power given by them. This righting power is equally effective in squaring the ship to the water, whether it be still water or rough wave water.

The under-water body can in no way help the ship to keep upright, since there is no kind of bottom on which she can be said to rest in the water. The most that any under body can do, either by shape or size, is to take *less* away from the stability given by the "shoulders" than some other shape or size of under body takes away. Size of bottom, therefore, or quantity of under-water body, *lessens* the stability of a ship, and has to be counteracted by the power of the "shoulders." In short, bottom tends to upset the ship; so much so, indeed, that if it be large and powerful, it may take more than the whole power of the "shoulders" to keep it down and prevent the ship from capsizing. In any case it weakens the effect of the "shoulder" by the whole of its upsetting power.

It is only, therefore, the surplus power of the "shoulder" remaining over and beyond what is employed to keep down the under body which is available for use in carrying a press of sail, or in supporting top weight out of the water. If there be any such surplus, it is necessary to find out how much there is, to see if it be enough to carry a press of sail, and enough also to carry top weight, as then the ship may be able to do without *ballast.*

By ballast, in the general sense of the term, is meant weights carried under the water, in contradistinction to weights carried above the water, or top weights. There are two ways of ballasting a ship;

one is by the real lading of heavy weights under the water; the other is by putting weights, which are not parts of the lading, nor essential parts of the ship, low down in the ship for the mere purpose of helping the "shoulders" to carry top weight; this latter being the old principle of ballasting.*

Weight placed under the water in either way may be said to have the following effects: first, by being under the water as far as the top weights are above it, it neutralizes the bad effect of these top weights and balances them. In this way under-water weight assists the "shoulders" in carrying top weight.

There is another way of looking at the effect of under-water weight in giving stability; it aids the "shoulders" in keeping down the under body. In this way, as well as in counterbalancing top weight, under-water weight helps the "shoulders."

Thus it is that there are three agents in stability—two arising from the shape alone, and one from disposition of weights. The shape and size of "shoulder" give stability of *form;* the shape and size of under-water body give instability of form. What of the power of the "shoulder" remains beyond counteracting this under body is the true surplus stability, or measure of righting power, for that form. This surplus is all that can be used for navigating a ship and carrying her top weights. If more stability be wanted, it can be obtained by *weight* alone. All the weights of a ship which have their common centre of gravity in the middle of the ship, just between the two "shoulders," neither help the stability nor hinder it. Only weight placed *below the middle of the "shoulders"* gives help and increases stability; and if the centre of all the weights of the ship, cargo and ballast, taken together, fall *above* the water-line, the surplus power of the "shoulders" may enable her to carry sail; if not, there is no resource left but to lower the weights in her, or to place ballast in her bottom; in other words, to supply the defect of *stability of form* by adding *stability of weight.*

As, therefore, stability of form is that power which the naval architect alone can confer on his ship—while stability of weight may afterward be regulated by those who lade, and control, and navigate the vessel—the form and action of the "shoulders" are the province in which the skill, contrivance and forethought of the designer of the ship can be most powerfully and usefully employed.

* Fincham states that in 1783 "three-decked ships" carried 480 tons of this dead weight.

CHAPTER XIII.

HOW TO GIVE A SHIP STABILITY WITHOUT GREAT BREADTH OF "SHOULDER."

Breadth of "shoulder," properly placed, gives power to stand upright and to carry heavy weights above the water; but cases often occur in which stability is sought and breadth of "shoulder" denied. This may arise from local causes, such as the narrowness of a dock entrance, or from a wish to obtain certain other qualities which may be inconsistent with great breadth.

In this case the dimension of length is the only one not limited, and the question arises, How can length take the place of breadth? To find out how stability may be given by length where the breadth is limited, it must be remembered that if the two *ends* are made very fine, in proportion to the *middle body*, they may be considered as having little effect in giving *increased* stability to the middle. Now, in *all* vessels with fine ends, very large portions of the two ends have merely stability enough to upright themselves, and have no power whatever to help the middle body to carry top weight. These two portions, therefore, may be taken as *neutral* parts of the vessel—neither helping the middle body nor requiring help from it, and therefore it simplifies the subject very much to leave them altogether out of the question.

Suppose fig. 10 to represent the *bow* of a ship, and fig. 14 to represent the *stern* of a ship at the mean depth of water. The form fig. 10 barely stands upright with its own weight. In like manner the form fig. 14 barely stands upright with its own weight, and a very slight elevation and depression of weights would make them absolutely neutral.

It is plain, therefore, that these forms, if taken as types of a certain kind of bow and stern, do not affect the stability of the middle body either way. These two ends may be assumed as types of the

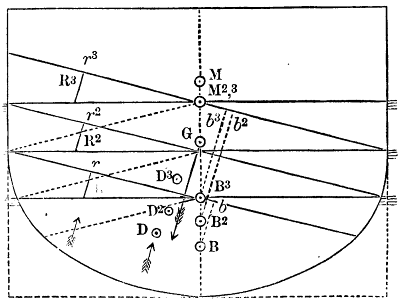

FIG. 6.

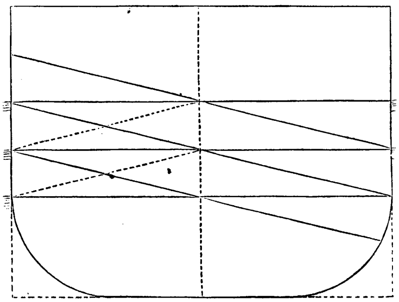

FIG. 7.

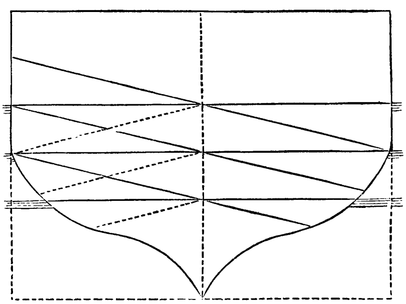

FIG. 8.

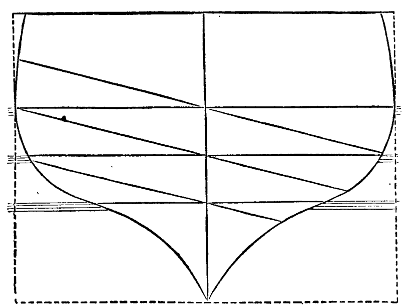

FIG. 9.

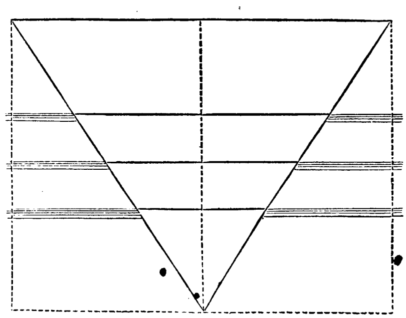

FIG. 10.

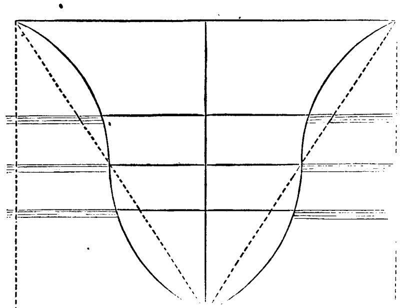

FIG. 11.

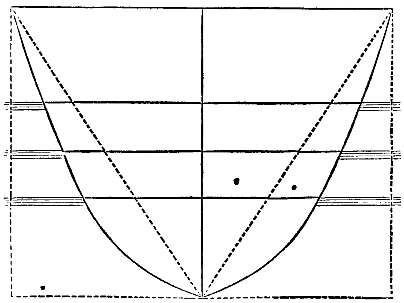

FIG. 12.

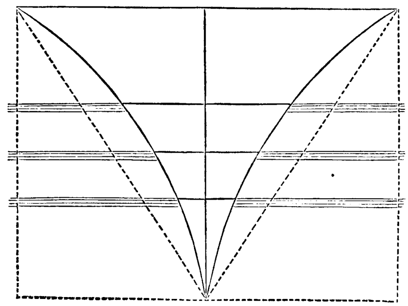

FIG. 13.

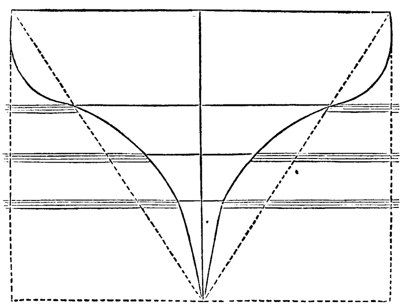

FIG. 14.

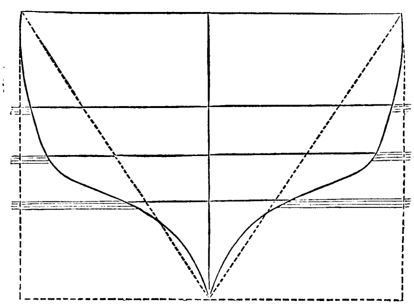

FIG. 15.

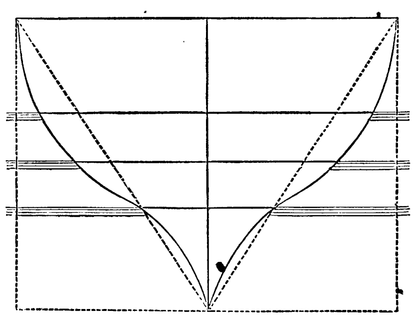

FIG. 16.

"*clipper*" bow and stern. Suppose fig. 11 to represent a "*bell*" bow, and it is seen that instead of being any use, this "*bell*" bow is unable to carry itself, and would require help to a very great extent. Fig. 12, on the other hand, taken as a type of the "*wave*" bow, has a powerful surplus stability at its deepest immersion, while only at its lightest immersion does it need help. Fig. 13, which is the extreme of the "*flare-out*" bow, is unstable at all immersions, and worse than helpless. It is plain, therefore, that the naval architect need not trouble himself to seek much help from any of these bows: it is to the *stern* that he should look for any help he may want in supplying the needful stability.

It is found, by long practical experience, that there exists a wide scope for obtaining power, stability and *weatherliness* to a ship of limited beam by a wise design of the *after* body.

A crank, narrow ship, may be rendered stable and weatherly by a very moderate alteration to the bulk and form of the after body. The secret of success consists in uniting with a very fine line under water a very full line at the surface of the water. Fig. 15 has great stability at its two deepest immersions, and is not deficient in stability even at its lightest. So great is its stability that very few *midship sections* even compete with it, and to most of them it would, at its deepest drafts, impart an enormous increase of that quality.

There is another point where the constructor can use the form of the stern with great effect, for the power of a middle body to carry top weight lessens as the draft of water increases. This is the same as saying that in proportion as heavy top weight presses the vessel more down in the water, so does this very depth in the water diminish the power of the midship body to carry its top weight. The reason for this is already known to be that bottom buoyancy increases both the quantity of the upsetting force and the advantage with which it acts. Now let it be observed how the after body can be used, so as exactly to counterbalance this defect of the middle body, and make good the stability of the ship in exact proportion to the increasing top weight which presses it down in the water.

The skillful architect will carefully cut away bottom buoyancy from the stern of the ship, which will enable him to make the "*run*" as clean and fine as he wants it to be. Nearer the middle the stern may be like fig. 15, and further aft like fig. 16; and finally like fig.

14. Each of these forms has a growing surplus of stability over that necessary to support itself, in something like the following proportion to the increasing draft of the water: Fig. 15—3 when lightest, and 7 when deepest; fig. 16—3 at middle draft, and 6 when deepest; and fig. 14 only 4 when deepest, but negative at the two other drafts. The more, therefore, of a form approaching to fig. 15 the constructor can put into the stern, the more powerful will be the resources he will have developed in the stern to aid the good qualities of the middle body, and to supply stability to do the work required exactly at the time and in the manner where it is most wanted.*

Constructors of the old school declaimed against a full after body and insisted on a fine run; but in truth there was no reason why either should have been sacrificed, in so far as concerned its practical use. On the bottom of the stern give the finest possible run: it is there where it is wanted, there alone where it is useful; so there give it to the utmost. Near the surface of the water, on the contrary, fineness of run is not only of no value to speed, but has many disadvantages of every kind. A wise constructor will seek there the stability he wants; since the buoyancy may be taken in large quantity near the surface of the water without impediment or increase of resistance; in short, as much as is wanted to make the vessel a good and stable ship. A mine of good qualities is here to be found, formerly comparatively unworked, mainly on account of a vague but widespread prejudice, having no better basis than the old saying: "Cod's head and mackerel tail." "Cod's head" meant simply the putting the fullness required for stability to carry sail in the bow; and "mackerel tail" meant taking it away from the stern. In former days it was not known that putting fullness in the bow, to create stability to carry sail, was putting it in a place to render that sail useless, for there it prevented it from carrying the vessel rapidly and easily through the water. The "wave" principle enables the modern naval architect to take away all that bluff buoyancy from the bow, where it does so much harm, by simply transferring as much or more buoyancy and stability into that part of the stern where, instead of doing any harm, it does good in every

* The form of the cross sections should be such that the volume of the wedges of immersion and emersion should be equal; otherwise the centre of gravity will rise during the motion of rolling, and produce an uneasy and very straining motion.

way, because it leaves the bow fine, of the form of least resistance, least disturbance and of greatest speed, while it transfers to the stern heavy weights which would harm the bow, and brings bulk where it gives room, buoyancy and stability.

Moreover, this room is given in that part of the ship where it is generally of the greatest value, both in a mercantile point of view and—in ships propelled by the screw—in a mechanical point of view; for it is exactly a form of stern, extremely fine and clean below, which is best suited for the screw's effective action, while the buoyancy and room above are all required in order to carry and counteract the great weights and mechanical forces due to the action of a propelling power in the after end of a ship.

CHAPTER XIV.

HOW TO MAKE A SHIP DRY AND EASY.

THERE is probably no point in naval construction subject to such variety of opinion as how to obtain ease and dryness in a ship head to wind, since there are several causes of seaworthiness and consequently counterpart causes which make a ship wet, uneasy and laborsome.

It is necessary to examine this subject to arrive at just conclusions, because these same causes also make it either easy or difficult for a ship to ride at her anchors in heavy weather or in a storm in the open sea when lying-to. The qualities proposed for consideration are among those which it is most important to decide accurately, because they are those which enable a ship to survive in safety the perils of the sea.

The first elements of riding easy are form and size of bow above the water. Some thirty years ago it was believed that a seaworthy, comfortable, safe vessel must have a high, wide, roomy, round, bluff bow, and that such a bow would enable a ship to throw aside every head wave and rise high and dry above the sea, the idea being that great over-water bulk and buoyancy was the grand consideration for securing the ease, safety and comfort of the ship.

It must be admitted that the example of the Dutch and of many others countenanced these opinions of the old school, and certainly any one who has seen how the Dutch fishing-boats and the pilot-boats, on the coast of Holland, ride out a storm on that dangerous and shallow coast, and ride safely over the breakers, would be apt to form a prejudice in favor of a buoyant, bluff bow.

There are many points in the structure of these craft which peculiarly fit them for their special purpose; their bows are more bluff even

than a circle, they recede inward under the bowsprit, so that they are the extreme and perfection of bluffness. But there could be no greater error than to take them as the type of seagoing ships, although it is a common blunder to fancy that the form which answers well for one purpose on a small craft answers equally for all purposes on the scale of a large ship. This natural belief has, however, been the parent of the greatest errors in naval architecture: it is an idol of tradition.

The best constructors of the present day hold a belief contrary to all this, and it is believed to be the experience of all intelligent seamen who have sailed in good vessels of the modern form, that the long, fine, hollow wave, or even straight-line bow, carried well above the water, rides easy and gently head to wind, when a full bluff bow could not live.*

Russell mentions an instance in which he illustrated this some twenty years ago.† He says: "I built four cutters of four large ships, all of the same dimensions, with four different shapes of bow—a "*wave*" bow, a "*straight*" bow, a "*parabolic*" bow, and a round, "*bluff*" bow. I allowed the four captains to choose each his own boat in the order of seniority. The oldest captain took the bluffest bow, of course, as the best sea-boat, and the "wave" bow was left for the last. In order to test their dryness and safety, head to sea, I had all four taken out together and forced through the water at the same speed by a steam-tug. The speed was steadily increased, until at last the water was coming over the bows of the bluff cutter in such quantities that the trial had to cease in consequence of the head sea pouring into her and filling her; the boat at the same time yawing about wildly beyond the control of her rudder, and threatening to go down. All this time the crew of the fine "wave" bow, at the same speed, were dry, easy and comfortable; and so there was an end, in

* A marked illustration of this fact occurred during a cyclone in the road of Funchal, Madeira, in March, 1858. An English sailing barque (built of iron), with the long fine bow, as above, rode out the gale and heavy sea with the utmost ease and dryness, without striking any yards or spars; while the full, bluff bows went on shore and were wrecked, with the exception of the U. S. frigate "Cumberland," which was only saved by the superior nature of her ground tackle and equipment, and a fortunate change in the wind at a critical moment.

† See the "Modern System of Naval Architecture," by Mr. J. Scott Russell, from which a great portion of this work is taken.

this case at least, of the prejudice that the full bow was the safe and dry boat."

On a large scale, however, the circumstances may be different, though observation of the effects of propelling vessels with full bows, head on to the sea, leads to but one conclusion, whether the full-bowed ship be propelled by steam against a head sea, or riding at anchor, or laid-to head to wind in a storm.

For the fullness of the bow does cause the ship to rise over the waves and to ascend on the coming sea; but, unluckily, it rises too high and too far, whence it follows that when it reaches the top of the sea a great quantity of the bow is left high and unsupported in the air and out of the water. In the next second the unsupported body falls with a rapidly-accelerating velocity, and by its *momentum* in falling plunges deep into the hollow of the wave. It is there met by the rising face of the next wave, which lifts it high in the air, when it again plunges heavily into the hollow of the next sea. It is *this* plunge into the succeeding sea which produces that violent shock that *no ship* can withstand for a long time. The English steamer "Great Britain" was an example of a vessel very fine below, with a great projection given to her above, under the idea of obtaining seagoing qualities; in her first trial, however, she received serious damage from a sea striking her in the manner above described. The same thing happens to a ship with a full out-of-water bow when she rides a gale; the bow receives from the ascending wave a rapidly-ascending motion till she comes to the top of the wave, and then, going over the crest, the whole weight of her unsupported, overhanging bow pitches down into the succeeding hollow; half buried, she is brought up with a violent shock in the following sea, and so she goes on *'scending* and *pitching* violently over every crested wave.

It will be seen that such a vessel *cannot* make much headway through the water, since the force propelling her no longer goes to speed. It goes toward driving her up on the ascending wave and down on the descending wave, and each heavy stroke of the water on the immersed bow is just so much force expended in stopping the ship, straining the timbers and *wasting* the propelling power. Effective speed loses, therefore, as much by such a form as ease and security.

But it may be asked, "How should a vessel move, if not up and

down over the sea?" To which it may be replied, "Up and down certainly; but not violently—as gently as possible." The movement up should be gentle, the vessel ascending just so much that the rising wave may not enter the ship, and descending on the other side just far enough to recover easily and without a shock at the bottom of the wave. In short, the motion of the vessel up and down should be a little less than that of the wave, and a little slower; and this desirable equilibrium is accomplished by a certain well-proportioning of the bulk of the over-water part of the bow to the under-water part. When the under-water part is very fine, the out-of-water part must be made fine likewise. When the under-water part is full, the out-of-the-water part will have to be proportionably full, and this proportion may be best given by so arranging it that the bow of the ship on the ascending part of the wave and on the descending part of the wave shall have nearly equal bulks, alternately exposed below the water-line and immersed above it.*

It is to be observed, however, that at the bottom of the wave the way of the ship exercises more force upon the approaching wave, to bury itself, than at the corresponding point of the top of the wave to rise out of the water. It is right, therefore, that the out-of-the-water part of the bow should be fuller than the under-water part—just enough to prevent her taking in a sea.

It is evident, therefore, that this approximate equality of fullness of bow above and below water has a tendency to make the sides of the bow between wind and water nearly straight, and also nearly vertical.

To this kind of bow there exists two in marked contrast, termed the "*flare-out bow*" and the "*tumble-home bow.*" The "*flare-out bow*" is often called the "*clipper bow;*" and there is another kind of it, formerly called the "*bell bow;*" and midway between all these is another sort of bow, neither tumbling home nor tumbling out: this may be styled the "*upright bow.*"

The "*bell bow*" was a favorite form with the builders of the packets trading between New York and Liverpool thirty years since, before the mail steam lines ruined that trade. It was a fancy of the builders of those fine ships to give the bows a form somewhat resembling a church-bell inverted, the swell outward, or "*flare out*"

* The bow of the "Great Eastern" has been said to accomplish this in *all* weathers.

as it is called, beginning about the "light line," and flaring out all around to the top of the bulwark, so that the forecastle occupied, as it were, the mouth of the bell.

There was, no doubt, something graceful and majestic about the aspect of these great bows, and they, no doubt, buffeted the waves triumphantly, but meanwhile the vessel was engaged in other work than its duty. Its business was to have gone not *up and down*, but *forward*, and this the bell bow hindered, and expended useful force in unnecessary but magnificent struggles. A bow was wanted that should elude the waves and pass them—escaping its enemy, not fighting it.

The clipper bow was next introduced to accomplish the design of the bell bow without involving its defects. Believing still in the advantage of a large flaring-out bow, the inventors of the clipper bow endeavored to obtain the supposed advantages of great buoyancy without the impediment produced by so much immersion in the water as the bell bow involved. "For this purpose," said they, "let us bell the bow laterally and draw it out longitudinally into a fine point; thus we shall preserve its bulk, but improve its shape."

Hence the fashion came in of prolonging the bulwarks of the ship at the level of the upper deck a great way forward, even 10, 20 or 30 feet in front of the actual ship, and there they were drawn out into a fine point above, and joined to the real ship about the water-line, everywhere with a kind of hollow flaring outside. This system certainly mitigated some of the evils of the bluff bell bow, and a large volume of buoyancy in the upper part of the bow, enormously in excess of the part in the water, was obtained.*

Yet it must always be regarded as a bad quality to have on the sides of a ship large overhanging projections, whether they "bell out" or "flare out." It is enough to say that they injure speed, and that they give uneasy motion to a ship, and that overhanging surfaces generally strike the water violently and uneasily. There can hardly result any good in a large flaring-out bow, whatever its shape may be; and it must be paid for in weight of material, in want of strength, in resistance to speed and in uneasy motion.

* The clipper vessels of Messrs. McKay of Boston and Hall of Aberdeen are very successful instances of the application of this system.

The most plausible recommendation of a "flare-out" bow is, that it throws the water off and makes a ship dry; but this is true only in a certain degree and in certain circumstances—not general—and rarely belonging to the cases now under consideration. If a vessel of fine and upright form in every respect have a slight "flare out" given to it at the top, it will turn over the tops of the waves and prevent some spray from coming on board; but if it really strike solid water instead of spray, it will do so with such force as to send that water into the air in large quantities; and if the vessel really take in green water over the "flare-out" bow, the danger to the ship produced by the mass of water in that place is so serious that no imaginary beauty can even justify such a defect.

It is believed that a much better form of bow is the nearly upright, or say the "tumble-home" bow, provided the construction of the other part of the ship will admit of it.

A dry vessel is made not by a bluff, overhanging bow to bruise, beat and buffet the waves, but by a long, thin, sharp bow to elude the waves, to pass through them so as never to break the water at all; in short, a bow so formed as to offer the minimum resistance to the passage of the vessel through the water, not in one direction merely, but in every direction all round the bow, above and below.

According to this fashion, the full projection of the bow should be on the water-line, which alone should first penetrate the waves, while the top sides of the vessel should "tumble home," and the whole be rounded off so beautifully and smoothly that nothing should either catch the water, stop the sea or break it. Observation and experience show that such vessels are the dryest and fastest in bad weather, as well as the easiest sea vessels, and, above all, the safest. If green seas ever come over the bows of such vessels, they have a much smaller quantity to take in, they hold much less, and what little does come in is much farther back, and consequently much less injurious.

The "tumble-home" bow has never yet become "a fashion," but vessels have been built with it which have proved themselves so much the better for it that it is thought that ultimately it will be generally adopted. For speed, easy riding at anchor, ease in a gale

of wind, or safety from the danger of shipping a sea, no other form is equal to it.*

There are two exceptions, however, to this reasoning: A very small vessel must have a large body above the water, if it be an open boat, to prevent its being swamped or filled with water; and where buoyancy cannot be given by other means, it may be given by flaring out.

Another case is that where the bow of a vessel is filled—as, however, it ought *not* to be—with extremely heavy weights, corresponding buoyancy must be placed on top of the bow to make it rise to the waves. This, however, is curing one evil by means of another.

No vessel designed for great speed ought to have much capacity under water in the extreme bow, and in no case should that part of the vessel be occupied with heavy weights.†

* A considerable number of the English blockade-runners captured during the late war were built with this bow. Though of small tonnage and limited beam, as a general rule they proved admirable sea vessels in *bad* weather.

† Therefore heavy pivot guns, in "the eyes" of sharp-bowed men-of-war, are great *mistakes*.

CHAPTER XV.

ON LONGITUDINAL STABILITY.

IF, in conformity with the maxims in the preceding chapter, the flaring bow (which causes a ship to pitch high, 'scend deep and make bad weather) is removed, a long step will have been taken toward making her easy and dry, and many common causes of unseaworthiness are thus obliterated. But there still remain some arbitrary matters, a choice of which goes far to enhance or improve the good qualities of a ship.

The over-water bulk above the water-line is removed; but in the choice of the *proportion* and *form* of the *water-line* itself much has to be settled on which may improve or injure the ship. It by no means follows that a vessel without overhanging or flare-out bows is either easy, dry, safe or steady, whether riding at anchor or going through a heavy head sea, since the form of the water-line is also a powerful agent in ease and seaworthiness.

The power of the sea to lift a ship's bow, and the force with which, when lifted and left by the wave, it falls into the hollow of the succeeding wave, depend on the form of the water-line, and on the place in which the water-line allows the weights of the ship to be carried. As regards pitching and 'scending, it may be inquired how the water-line can be formed so as to make the ship ride and drive easiest through the sea?—understanding by "easy" that she shall rise and fall gently, slowly and not far. Fortunately there is a measure which tells this exactly. The power of the slope of a rising sea to raise a ship is measured by the same elements and methods as those by which we measure the power of the water to support the ship sideways against the depressing power of her canvas on the lee side, or enable her to carry a heavy load upon one side.

The power of a head sea to lift the bow of a ship is, therefore,

measured in the same way as lateral stability, only the elements are reckoned *lengthwise*, instead of being taken across the ship.* To proceed, then, to the consideration of measuring the tendency of the sea to raise a bow which has been depressed under its natural water-line, let it be imagined that the bow (fig. 17) is pressed under water by a displaced weight moved from O, the middle of the ship, and placed in the bows at W. This weight presses a wedge-like part of the bow into the water, and raises the stern out of the water. The wedge of immersion of the bow acts by its buoyancy at its centre of effort with a righting force proportioned to the bulk of the wedge, and to the distance of the centre of effort from the point O. It acts in *length* just as the wedge of lateral immersion does in width. Its *raising power* is to be found, therefore, by multiplying its *volume* into the *distance of its centre of effort* (R) from O. The power of the sea to lift the bow of a ship depends on the *bulk* of the bow immersed, the *length* of the bow, the *fullness* of the water-line and the *place* of that fullness. If a water-line be *full* forward, it will have great lifting power; if *fine* forward, small lifting power.

Having measured the power of a sea to lift a given bow, it is necessary to measure the force with which, when left unsupported, it falls upon that sea. That depends upon the weight left unsupported and on the point at which it acts. If the weights lie far forward on the bow, it will fall with great force into the water, descending with a speed proportioned to its *distance from the centre*, and plunging to a depth proportioned to the *square* of its falling velocity.

From these two considerations it is plain that a ship in 'scending will be raised out of its horizontal seat on the water-line in a very high proportion inverse to its fineness of bow, and that, in pitching, the ship will plunge less in proportion as the weights left unsupported are removed from the extremities toward the middle body of the ship. The importance in trimming a ship of so distributing her weights as to diminish their effect in causing her to pitch heavily, is therefore evident. A bow fine at the extremity, but taking fullness farther aft, makes a ship much easier than one which is leaner aft and fuller forward.†

* There is therefore a *longitudinal* meta-centre.

† Since longitudinal stability is the antidote to pitching and 'scending, lateral stability may be said to ease, increase or diminish the motion of rolling. A "juste milieu" must be sought in either case.

The form and proportion of the stern has not here been noticed, since the stern of a ship has not to be driven against a sea, and in all ordinary practice is so sheltered from it that overhanging form and unsupported weight, which would be a source of insecurity in the bow, may be tolerated with safety and convenience. What is said of the bow may therefore apply only to the stern in a very modified form.

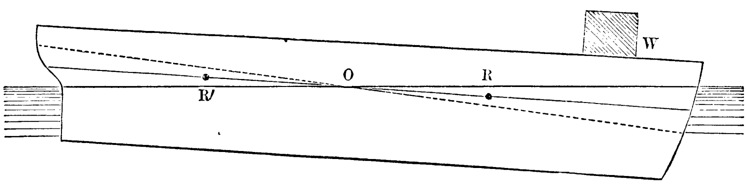

Fig. 17.

CHAPTER XVI.

ON THE QUALITY OF WEATHERLINESS, AND HOW TO GIVE IT.

THE nature, cause and cure of crankness or instability having been considered, it is now known how to make a ship stable under every ordinary condition of load, by giving her power of "shoulder" to stand up stoutly and carry a heavy press of canvas in a stiff breeze—a quality which is therefore called *stiffness.*

This quality of stiffness under sail, or uprightness, requires, as an addition to it, *weatherliness*—a virtue as opposed to *leewardliness.* A leewardly ship is liable to be driven with the wind, though her head be laid in an opposite direction. By leewardliness ships drive broadside on toward a lee-shore instead of lengthwise through the sea, and so, lacking weatherliness, are lost.

Next, therefore, after stiffness comes weatherliness to go in the direction intended—to make headway across the wind and against the wind, instead of driving broadside to leeward.

This quality is to be obtained by considering an entirely different aspect of the vessel from that hitherto examined. The ship has been viewed through her breadth merely; she must now be looked at through her *length* and *depth.*

The full-length side view of a ship, as she sits upright in the water, presents a much larger extent of surface than the cross view of her breadth.

A ship of 36 feet beam and 18 feet depth in the water, may have 648 square feet of *immersed cross section*; and, in order to force the vessel through the water, those 648 square feet of *midship section** must be pushed in the direction of the length of the vessel. This the propelling power must do; and supposing it requires a pressure of 30

* Generally known as the ⊗ (or *dead-flat*) section.

lbs. to push each foot through the water at the rate of 10 miles an hour, if the sails of the ship have enough pressure of wind upon them to give this force of 30 lbs. for each square foot of section, the vessel will go ten miles an hour before the wind.

This, however, is *not* the thing wanted; for the sails may be so trimmed, and the vessel's head so laid, that by means of the obliquity of the sails to the course, and of the course to the wind, the ship shall sail technically "on the wind." Now it is the business of the seaman to lay her head in the proper direction, and to see that her sails are trimmed to the proper angle; but it is the naval architect's work to see that the *form* of the vessel prevents her driving to leeward.

It must be understood, therefore, that when the ship does not run straight before the wind, but lies obliquely to it, the force of the winds acts in two directions. Partly it forces the ship its own way or to leeward, and partly it forces her in the direction in which her head is laid, or to windward; the practical question being how to make the first as *little* as possible, and the second as *much* as possible, —in short, how to make the ship *weatherly*. This the naval architect has to do.

The means by which weatherliness is given consists in interposing the greatest possible obstacle between the leewardly part of the wind and its effect. The ship must be so constructed that it will be hard for her to drive to leeward and easy for her to go to windward; and the antidote to leewardliness is *large longitudinal section*. As 648 feet of cross section are to be driven in the course of the ship, there must be much more than this, and as much more as possible, in the other direction at right angles.

If the constructor can put six times 648 feet between the ship and her going to leeward, she is made six times as hard to drive to leeward as to windward. By this means it is contrived that her progress to leeward shall be very small in comparison to her progress to windward, even when the sails are so trimmed that there is as much force pushing her the one way as the other.

In considering weatherliness, therefore, he has only to see by what means as great a surface as possible can be interposed in the water, so as to prevent the ship being forced to leeward. If the ship can be made six times as long as she is broad, and preserve her depth below the water all the way to an average of 18 feet—or say 17 feet

at the bow and 19 feet at the stern, which is the same thing—then she has a longitudinal section 216 feet long by 18 feet deep, presenting, in the whole, a resisting area of 3888 square feet.

Thus it is that a considerable excess of length beyond breadth is necessary to give weatherliness, and therefore it will be plain that unless adequate length be given, all the stiffness to carry sail, for which so much breadth of "shoulder" has been given, will be thrown away; because if the ship can carry sail merely, and that sail only force her to leeward, it is useless. Stiffness, therefore, or breadth of "shoulder," must have *length* to back it or it is worthless.

The area of longitudinal section to give weatherliness must bear a due proportion to stiffness and to area of cross section. *Stiffness* measures power to drive the ship under canvas; *cross section* measures the force necessary to drive it ahead; and *longitudinal section* measures resistance to being driven to leeward.

Another element which comes in to assist weatherliness is the ease with which the fine shape of a vessel will permit her to be driven endwise through the water, and it is a fact that some vessels are so well contrived for this purpose as, by sharpness alone, to reduce the power necessary to propel them to *one-twelfth* of what it would be if they opposed to the water simply a flat bow.

In the example the area to resist leeward motion has been made greater than that resisting forward motion in the proportion of 6 to 1; and if the form be so fine as to reduce the resistance to forward motion still further in the proportion of 6 to 1, the combined effect will be in the proportion of 36 to 1. This would be a successful achievement, for it would reduce the loss of motion by leewardliness to a very small quantity.

It is generally reckoned that the extent of sail which a ship can carry in a fresh breeze may be six times the area of her longitudinal section in the water. This, in the size of ship taken as an example above would give an area of sail equal to 3888×6 or 23,328 square feet. Now this area of sail has got to propel the vessel with an effective force of 30 lbs. to each square foot of midship section, and as there are 36 square feet of canvas for every foot of driven section, the result is 30 lbs. divided over 36 feet, or $\frac{5}{6}$ of a lb. as the required force of the wind on a square foot. Therefore it is plain that a little less than one pound pressure on each square foot of sail,

effective in the direction of the vessel's course, would be necessary to propel her ten miles an hour, and this a very moderate force of wind would accomplish.

But an equal force would, with a given trim of sail, be pressing the ship to leeward. The effect of this other force would, however, be expended on six times the area, and that area has six times as much resistance to leeward as ahead. Under these circumstances the motion through the water being as the *square root* of the force, the leeward motion would be to the onward motion as the square root of 36 to 1, which is of course 6 to 1.

The result is that the ship is driven six miles forward while she is driven one mile to leeward, and such a vessel would be an ordinary *full,* but *not fast nor weatherly* ship.

There are three ways in which the naval architect can improve the weatherliness of this ship. He may diminish the area of the cross section, fine the shape of the ship so as to offer less resistance, increase the area of the longitudinal section, and give increased resistance to leeway by increase of length or of depth; or he may do any or all of these things at once.

The process stated above assumes that the naval architect is at liberty to give sufficient longitudinal area by the disposition of the body of the ship; that is, that he can have such a draft of water and such a length of body as he may select. When his ship is not of suitable dimensions, he has to resort to various expedients. If he has not depth of water enough naturally in the body of his ship, he has to add timber or *deadwood* to increase the weatherly section of the ship. When he adds this on the bottom it becomes *keel* or *false keel,* and is often carried to a great extent. If this is not enough, he adds further deadwood in the shape of stern and *cut-water;* and to assist and balance these he adds as much deadwood as he can in the *run* before the rudder. It is thus that vessels with a small body may obtain a great weatherly section; and racing vessels, yachts and clippers are frequently built in this manner to so extreme an extent as to be nearly all deadwood and keel and little or no body. A vessel of this sort becomes a mere racing phenomenon. But, nevertheless, by extending deadwood in every direction—before, abaft and below—extraordinary weatherliness may be obtained at the sacrifice of *capacity.*

When these arrangements fail, or cannot be applied, there remain other expedients for securing weatherliness. The *lee-boards* of the Dutch craft attain this. On the shallow, sandy coast of Holland no deep keel is possible, and therefore the Dutch vessel at sea would drift to leeward for want of depth of body; to provide against which she carries on her lee side a large flat board of enormous area, which is let down into the water in such a manner that the whole of the board must be driven on the flat side, leewardly through the water before the vessel can make leeway. One of these *lee-boards* is carried on each side of the vessel, so that either side when it comes to leeward has its own "*lee-board*" for alternate use. This is the Dutchman's substitute for windwardly section, of which his small draft deprives him.

Another substitute has been used, termed a "*sliding keel*" or "*centre-board*," and is formed by providing a hollow, upright aperture in the middle of the vessel, in which a large flat board is contained, so that it can be lowered through a slit in the bottom into the water.*

These, however, are expedients merely in the last resort, when the naval architect is denied the means of giving his vessel due proportions. If due length can be given, it is much wiser to obtain weatherliness by proper length and fine form than to seek artificial expedients, either in "*lee-boards*" or "*centre-boards*," or in exaggerated deadwood; but of none of these expedients should he be ignorant; and it is better to obtain weatherliness by all, or any of them, than to have a leewardly vessel.

In these days a sailing vessel of ordinary form is generally about six times as long as broad. To drive her at the rate of ten knots an hour through the water requires about 48 lbs. of force for each foot of her midship or greatest cross section. Suppose the vessel has 100 square feet of immersed midship section, requiring a force of 4800 lbs. to give her headway, and that the sails are placed at such an angle that they press equally forward and over, or so that there shall be equal forces causing headway and leeway—there will then be a force of 4800 lbs. causing leeway, and this force is spread over 600 square feet, forming the immersed longitudinal section of the ship. On each square foot of this section there will be, therefore, only one-*six-hun-*

* "*Centre-boards*" are only used in yachts and other small vessels.

dredth part of 4800 lbs., or 8 lbs. per square foot of section. This 8 lbs. will cause a leeway of less than 2 *knots*. This example shows the great advantage obtained in sailing vessels by large hold of the water. It is plain that by giving this vessel greater length and depth, her resistance to leeway might be doubled, so that the force causing leeway would be divided over double the area, and be reduced to 4 lbs. per foot intead of 8, and this 4 lbs. per foot would only give a leeway of 1.25 knots per hour.

Table VII. shows what happens when the sails are set at an angle of 45° to the course of the ship, and the wind is right abeam. In these cases there is equal pressure along the ship's course and to leeward. The lesser leeway arises from two causes: the greater area of longitudinal section than of midship section and the fineness of the shapes. It will be seen that in the full form of vessel the leeway, under the pressure that produces 12 miles an hour, is 2 miles an hour. Under a pressure of 1 lb. on the sails, the headway is 10 miles an hour, and the leeway $1\frac{2}{3}$ miles. This would be the case in a fresh breeze carrying all sail. When the vessel is proportioned for greater speed, with a greater proportion of length to the same area of resistance and a finer form, the leeway is reduced and the speed increased.

These calculations are made upon the supposition that a vessel's resistance to leeway is the same as that of a thin plate equal to her longitudinal section. But vessels with round bilges let the water pass underneath them from one side to the other more easily than a vertical plate, and so do all ships when they careen much. A little more leeway must be allowed for in these cases.

TABLE VII.

Leeway and Headway.

The sails set at an angle of 45°, the wind abeam. The force of the wind reduced to allow for obliquity.		*Full form of ship, with the cross section to the longitudinal section as 1 : 6. 36 square feet of sail area to a square foot of cross section.*				*Finer form of ship, with cross section to longitudinal section as 1 : 8. 36 square feet of sail area to 1 square foot of cross section.*			
Effective force of the wind per square foot of sail. Leeward.	Effective force of the wind per square foot of sail. Ahead.	Drifting force to leeward per foot of longitudinal section.	Driving force ahead per foot of cross section.	Drift to leeward.	Speed ahead.	Drifting force to leeward per foot of longitudinal section.	Driving force ahead per foot of cross section.	Drift to leeward.	Speed ahead.
Lbs.	Lbs.	Lbs.	Lbs.	Miles.	Miles.	Lbs.	Lbs.	Miles.	Miles.
0.2	0.2	1.2	7.2	0.8	4.5	0.9	9.6	0.6	6.0
0.4	0.4	2.4	14.4	1.1	6.3	1.8	19.2	0.9	8.5
0.6	0.6	3.6	24.6	1.3	8.3	2.7	28.8	1.1	10.4
0.8	0.8	4.8	28.8	1.5	9.0	3.6	38.4	1.3	12.0
1.0	1.0	6.0	36.0	1.7	10.0	4.5	48.0	1.5	13.6
1.2	1.2	7.2	43.2	1.9	11.0	5.4	57.6	1.6	14.6
1.4	1.4	8.4	50.4	2.0	12.0	6.3	67.2	1.7	15.8

CHAPTER XVII.

HOW TO MAKE A SHIP HANDY AND EASY TO STEER.

THE first part of *handiness* consists of *balance of sail;* the second, of *balance of ship;* the third, of *proportion of rudder.*

Unless the sail be balanced, the ship will *drive* with the wind, instead of moving toward her destination; for if there be a sail on the forward part of the vessel only, the wind will force the forward part to leeward, and she will drive head foremost; and if there be a sail on the after part of the vessel only, her stern will go to leeward, and she will drive stern foremost; wherefore, in order that neither of these things shall happen, the sail on the fore part of the vessel must be so placed and proportioned to the quantity and place of the sail on the after part that they shall *exactly* balance one another in effect, so that neither one nor the other can prevail. This is virtually to take away from the wind all power of determining the direction of the ship; and the seaman, by properly regulating this balance of sail, can keep the ship's head in any direction he pleases.

This is balance of sail, but it depends on another element—namely, the balance of ship. The effect of sail at the bow may be exactly balanced by that at the stern; yet, nevertheless, there will be no enduring balance if the bow be more easily forced to leeward than the stern, for then the head of the ship would go around to leeward. A balance of sail forward and aft, and a balance of ship lengthwise in the water—the one called "*trim of sail,*" the other "*trim of ship*"—the forethought of the naval architect must provide. To maintain this equilibrium depends upon the ability and thoughtfulness of the commander of the ship.

It is thus only that a handy ship is obtained and kept so. The sails *must* balance, the body *must* balance, and both *must* be kept

together in perfect trim, while the seamanship of the commander, the hand of the helmsman and the blade of the rudder do the rest.

Something more, however, can still be done by the naval architect to give the sailor complete command over his ship. The balance he has established is enough to deprive the wind of the control of the vessel and give it to the seaman; but the ship may still require from him the exertion of very great controlling force when he wishes, in the course of his manœuvres, to change its head rapidly from one course to another. Balance of sail and of body will help him to do this, but it will not help him to do it *quickly*.

To make a vessel very handy and turn very quickly her longitudinal section should be *deep*, rather than long; and when its extreme length is decided, its effective length should be diminished as much as possible by removing longitudinal area from the ends and placing it near the middle. Above all, much *cut-water* and *fore-foot* makes a vessel unhandy and slow to come around.

It is better, therefore, to have deadwood *aft* than forward, but removed from both ends as much as possible. Rounding off the *fore-foot* and shortening the *heel* are the most effectual ways to make a ship handy without injuring her other qualities—the effect of *heel* and *fore-foot* being to cause *gripe*, or resistance to turning, which is the contrary of handiness.

With balanced ship and balanced sail, good trim and little gripe, not much can be wanting to handiness. The *rudder* must do the rest. The rudder, however, is nothing but a power to control; it merely acts as a drag on one side; it always *diminishes* speed in turning the ship; and the cleverest helmsman is he who uses it *least*, the best ship is that which wants it *least*, and the best sailor is he who does most without it. A steersman always yawing a ship about steers badly. A ship requiring much helm is badly trimmed, and sails requiring much rudder are badly set or balanced. Nevertheless, it is above all things necessary that the rudder should have ample power —great power, seldom used. A ship that will run along for hours with scarcely a touch of the helm is a ship well trimmed and sailed; but when needed, the rudder must be able to turn a ship short and sharp around, and this may save her in an emergency.

The way to give power to the rudder is to proportion it to the *length* of the ship, for a long ship requires a broad rudder. It is

thought that for every 100 feet in the length of a ship she should have 2 feet of breadth with one foot added. Thus a ship 100 feet long needs 3 feet breadth of rudder; 200 feet long, 5 feet breadth; 400 feet long, 9 feet, and so on.*

As to the shape of the rudder, there is not much in it. Some say the top of the rudder is the most valuable part, for the water there has the most effect, and that the rudder should be widest there; others say it should be widest at the bottom, for that there width is most effective. Both are crotchets; but still there may be something peculiar in the case of some ships to render both exceptionally true.

The fault of having the widest part of the rudder near the load water-line is, that there a rough sea may strike the rudder most heavily. There is less harm in making the rudder widest near the keel, for, being well buried under water, the wave surface of the sea has less action upon it, and in bad weather the helmsman is not liable, as in the first case, to have the helm taken out of his hand. But on the other hand the heel of a wooden screw-ship may be, and probably is, her weakest part, and to put more strain than necessary on a weak place is unwise, to say the least. The best way is to have the widest part of the rudder near its centre, rounding it off toward the top and heel, the one to keep it from the force of the waves, the other to protect it from the ground in a narrow and shallow channel.

It will always be a question about the quantity of rudder to be given to a vessel destined for any special purpose. If the ship is always to be committed to wise hands, who will never use more than is necessary, it is safe to give plenty of rudder, leaving it to their discretion to use it as they may desire, because, with powerful rudders, manœuvres can be performed which are impossible with small ones. To be able to turn very fast will often give a ship the advantage of another; and in a contest for victory, or of sport for a challenge cup, ability to execute difficult manœuvres rapidly is often in itself a source of success. A ship well in hand is often better than one which is faster but runs wild. Therefore, put into wise hands a powerful rudder.

* Of all descriptions of rudder for *long* vessels, the "equipoise" or balance rudder is the most in use, as its advantages are great breadth without any more increase of strain on either *pintles, gudgeons* or *wheel ropes* than is produced by an ordinary rudder of one-third the size.

CHAPTER XVIII.

OF BALANCE OF BODY AND BALANCE OF SAIL.

HANDINESS, therefore, or the ready obedience of a ship to the will of her commander, arises out of the due combination of balance of sail, balance of body and power of rudder, for without these a vessel steers wildly, and can hardly be controlled in her movements.

When, either through want of balance of sail or balance of body in the water, the ship shows a tendency to *fall off* or *fly-to,* she is said to have two opposite defects—the first called *leewardliness,* the other called *ardency.* These defects must be corrected either by *trim of sail* or *trim of ship.* If not corrected, they must be counteracted by the action of the rudder; but as the rudder is a sort of *stop-water* applied on one side, and in no case a help, speed is lost in the degree in which the rudder is used. The tendency to fly into the wind, and the tendency to fall off from the wind, or ardency and its opposite, require remedies of opposite kind. Ardency implies that the ship must always carry *weather helm;* want of ardency, that she must always carry *lee* or *slack helm.* Of the two evils, ardency is considered the less, and it is usual, therefore, to trim a ship so that she shall always carry *a very little* weather helm.

The point in the length of a ship on both sides of which the sails balance is called "*the centre of effort of the sails;*" the point in the water on both sides of which, fore and aft, the body balances, "*the centre of lateral resistance of the ship.*"

In a state of perfect trim of sail and trim of ship—that is, when a ship is so perfectly balanced as to be neither ardent nor leewardly, requiring neither lee nor weather helm—the centre of effort and the centre of resistance meet exactly in the same point of the length of the ship,* and so the effort of sail and resistance of water, fore and aft, exactly counterpoise one another.

* That is, they are exactly *over* each other.

Unfortunately, there are but few ships so constructed as that this coincidence shall take place and be maintained at all speeds, and in all states of wind and sea and weather.

In a perfectly-formed "wave-line" vessel the coincidence of the two has been found to be exact and perfect; but by a very slight deviation from this form the perfection of this balance is at once deranged. In order to correct this want of adjustment, the centre of effort of the sails has to be moved forward, and in certain cases very considerably so.*

In every vessel built on the old system, this derangement of balance had to be taken into account and allowed for as an element in the original construction of the ship. Unluckily, it was sometimes allowed for by guess merely, and therefore nothing was so common as to hear that a new vessel had to undergo an entire change of arrangements† from the impossibility of managing her, owing to the centres of effort and lateral resistance not coinciding. In such a case the usual remedy (if the error was slight) was to *rake the masts* either a little forward or a little aft, in order to correct the balance of sail, or else to put on a little deadwood forward or abaft, or to add a tapering false keel—all for the purpose of restoring the lost balance; and when these expedients failed, the masts, or some of them, had to be shifted—an arrangement not only expensive, but deranging to a great extent the interior economy of a ship of war.

One of the great advantages of the "wave" system is, that the centres of effort of sail and of resistance of body coincide. It is impossible to adjust these two centres to a more perfect balance for practical use, so as to have a ship easy to steer, requiring little helm, quite under command and handy, than by merely taking care that they coincide in the same point of length.

But this perfection of balance and handiness is not to be obtained without an equal perfection of wave form, since every deviation from *exact* truth in the form of a ship will exhibit derangement of balance. In exact proportion as any part of the bow is filled up beyond the pure "wave" line, the balance of sail and of resistance will be dis-

* The English line-of-battle-ship, "Duke of Wellington," for example, in which the whole of the masts and sails had to be placed forward from the true centre of resistance the space of 14 feet.

† That is, as regards her masting and sail draft.

turbed, and it will be necessary either to correct the shape of the body, or to remove the centre of effort of sail forward, or to shift the centre of lateral resistance aft. The reason of this is that the "wave" form is the form of least resistance, the truth of which is practically shown when the vessel (in deep water) shows no bow wave or breaks no water at the bow. Any untruth in the "wave" form at once shows itself in broken water or the well-known wave at the bow, which is bad. The appearance of this obstacle to progress shows exactly where there is an expenditure of undue force, and it is this undue force and unnecessary resistance which deranges the centre of lateral resistance of the ship, and shifts it forward. Its tendency to do so increases with the velocity of the ship. It is to meet this shift of pressure and to counteract it that the centre of effort of the sails must follow it forward. But no one can tell precisely beforehand how much any deviation from truth in the form of a ship will remove the centre of resistance, and therefore it is impossible to say what change in the centre of effort may be required to correct it. Unluckily, also, the deviation arising from incorrect form varies with the speed, so that the difference which will restore the balance is not the same for all speeds.*

There is another curious cause of deviation between the centres of effort and resistance. If a ship has a long, straight middle body, she will have a tendency to ardency, arising from length alone.† Even if the two ends be perfect wave ends, a long, straight middle body will have this tendency to disturb their balance. Of this singular phenomenon of deviation arising from length of middle body, an exact measure can scarcely be given; but the explanation is believed to be that a long ship, by the mere progress of its sides through the water, drags with it and puts into motion, by adhesion merely, so great a quantity of the water in its neighborhood that at the last, when near the stern, the water has ceased to offer any lateral resistance, because it has already received the same motion as the ship itself. At the stern, therefore, there is little left to resist the ship; and so, from lack of stern resistance, the after part loses power to

* No certainty, therefore, is to be obtained on this point, except by the preservation of the absolute truth of the "wave" form.

† It is probably on this account that many of the long vessels of the navy are found unable to carry any after sail without a great excess of weather helm.

carry after sail, and the ship becomes ardent. Even wave ends, therefore, will not compensate for this fault of long middle body. If the inquiry be made as to what limit this extends, it may be replied that, in a vessel with 60 feet beam and 90 feet middle body, it has not been sensible; but with similar ends and 100 feet middle body it has become a very sensible quantity. This deviation from the true form, while it is attended with mercantile advantages of capacity not to be regarded lightly, must be taken with its disadvantages.

In order thoroughly to apprehend the nature of this fact, suppose a thin, flat board moving edgewise through the water, and also pressed sideways by a force like the wind at right angles to it. Next consider what happens to a particle of water placed to leeward of this thin board. When the board first touches it, it has no leeward motion, but it immediately acquires it—small at first, but gradually growing, as the following parts of the board successively press it, and as each succeeding part of the board finds the water already put in leeward motion, it follows that the latter parts of the board are in contact with particles already moving so fast to leeward that, unless they accelerate their leeward speed, they will experience no lateral pressure from the water. Hence two effects must follow—the after parts of the board will have less pressure on them than the fore parts, and also the after parts will be moving to leeward faster than the fore parts. This is the explanation of the ardency produced by a long, parallel middle body.

Another source of derangement between the centres of effort and resistance will be found in any deviation from the water-line which may be produced in the change of shape in the vessel as she heels over from the pressure of a side wind. If a full part of the ship comes into the water on heeling over, that part will cause its own special resistance, and, in so far as it deviates from the true form, will cause an excess of pressure at that point and a derangement of the centres of balance; it will, in fact, make the vessel behave as if she had a curved keel, concave to the wind. Another reason why heeling produces ardency is, that it forces the centre of effort of sail to leeward, so as to make the masts exert a horizontal leverage to bring the ship's head into the wind. Apart from heeling, there is also a small element of ardency in the case of fore-and-aft sails, from

their centre of effort being invariably to leeward. Theoretically, the bellying of square sails should tend in the same direction, but it is believed that this cause is not appreciable in practice.

There is another cause of deviation which must take effect in all vessels of whatever form, but its action is slight, and is not, except in the case of very great length of middle body, of sufficient consequence to rank as an element in the adjustment of the centres; it is the resistance of the adhesive film of water on the skin of every ship. This adhesive film is scarcely a visible thickness at the bow; it increases uniformly with the distance from the bow toward the stern, where it is greatest; the film seems to grow as it goes by attaching to itself another and another outside film on each foot of progress, and, all added together, the entire film has the thickness of a foot or more on each side at the stern. This may diminish the lateral resistance, but it seems just enough to give the vessel that degree of ardency which is preferable to the smallest degree of the opposite quality, and when no other source of derangement than this remains, the naval architect may congratulate himself on having completed that part of his business satisfactorily. One other source of disturbance will *always* remain, which he can neither foresee nor prevent: the winds and the waves will always act irregularly on the ship. But when he has done the preceding parts of his work well, he will leave the mind of the helmsman and the action of the rudder perfectly disengaged from all unnecessary work, and free to be disposed of in that cautious, ready and prompt counteraction of the winds and the waves which is the business of the thoughtful and the watchful seaman.

It is the duty of the constructor to make an exact calculation on the body of his ship, so that when loaded in the water to its proper line, the lateral resistance to leeway shall be found at its proper point in the length of the ship. This central balancing point, or "centre of lateral resistance," should be a little *abaft* the centre of the ship.

His next duty is to make an exact calculation of the sails of his ship, so that the pressure of the wind upon all the sails may have its central balancing point rightly placed in reference to the centre of resistance of the ship. This "centre of effort of sail" should be so adjusted as neither to be too near the bow nor too far from it. In "wave"-line vessels it is necessary to place the centre of lateral resistance of ship and the centre of effort of sail precisely the one over

the other; but in the forms of ordinary sailing vessels it is found necessary to have the centre of resistance a little *abaft* the middle of the ship, and the centre of effort of sail a little *forward* of the middle. To bring the centre of resistance aft, a ship is generally trimmed two feet by the stern; and to carry the centre of effort forward, additional sail, beyond the quantity proper for a vessel on an even keel, is carried on the bowsprit. By these means a distance of about *one-twentieth* part of the length of the ship may be placed between these two centres; and in most ships this is sufficient for the purpose. Table VIII. shows the distance to which trimming the ship by the stern will shift the centre of resistance backward.

But, however exactly the naval architect may have designed the ship, the trimming of the sails and of the ship must remain essentially a part of the seaman's duty, because the trim of the ship is chiefly a question of stowage of cargo or disposition of weights, and as this is always varying in a steamship, and can always be ill or well done in a sailing vessel, the original constructor of a ship, however wise, can never dispense with the watchfulness and judgment of the commander of the vessel.*

There is another cause for constant watchfulness as to trim, in the fact that most ships shift their centre of lateral resistance *forward* as their speed increases, and therefore require after sail to be diminished as the wind rises. The *first* duty, therefore, of an officer in command of a *new* ship, or one starting on a *fresh trim,* is to determine the proper balance of ship and sail.

He should shift weights forward and aft until he finds the trim which will enable him to carry the proper sails; and having done this, should carefully study how the quantity of sail must be adjusted in the various degrees of strength of wind, so as to measure this balance. It is in this way that a skillful commander will often make a ship fast by trim alone, whereas an ignorant one will fail to find out the good points in a ship, because he does not *systematically* look for them by studying her performance under every variety of trim at his command. In this way the commander, even more than the constructor, makes the character of the ship.

The sum of what is known in regard to balance of body and balance of sail and trim, is therefore as follows:

* And the commander should thoroughly understand the design of the constructor.

The *middle* of the length of a ship is the *balance point* or centre of lateral resistance, if she be nearly at rest, drifting to leeward, and on an even keel with upright stem and stern-post.

Trim of ship by the stern shifts the centre of lateral resistance from the middle toward the stern. An *inch* of trim to a *foot* of draft shifts the centre of lateral resistance abaft the middle by one-*one-hundred-and-forty-fourth* part of the length of the ship. Or the excess aft, represented by a fraction of the *draft amidships* (say *one-sixth*), multiplied by *one-twelfth* of the ship's length, gives the shift abaft caused by trim. *Raking* the *stern-post* and *rounding* the *stem* also shifts the centre of lateral resistance forward or aft.

Raking the stern-post shifts this centre forward *one-quarter* of the rake. Rounding the stem, so as to make it a quarter of a circle, shifts the centre aft by about *one-tenth* of the *draft* at the stem.

In ordinary-shaped ships these last counteract each other, and if the draft fore and aft be nearly equal, the centre of lateral resistance at rest is in the *middle* of the length.

To find what amount of trim will balance a given amount of rake of stern-post, the following *approximate* formula may be used:

$$\frac{\textit{Trim}}{\text{Rake}} = 3 \text{ times } \frac{\textit{Draft Amidships}}{\text{Length}}$$

Or else refer to the following table, calculated from the formula:

TABLE VIII.

Showing Rake of Stern-post required to Balance a given Trim or Difference of Draft Forward and Aft.

Inches of difference of trim to every foot of draft amidships.	Rake of Stern-Post.		
	In inches to every foot of the length of vessel.	In fractions of length.	Decimal fraction of length.
0.5	.17	$\frac{1}{72}$	0.01389
1.	.33	$\frac{1}{36}$	0.02778
1.5	.50	$\frac{1}{24}$	0.04167
2.	.67	$\frac{1}{18}$	0.05556
2.5	.83	$\frac{5}{72}$	0.06944
3.	1.	$\frac{1}{12}$	0.08333
3.5	1.17	$\frac{7}{72}$	0.09722
4.	1.33	$\frac{1}{9}$	0.11111
4.5	1.50	$\frac{1}{8}$	0.12500
5.	1.67	$\frac{5}{36}$	0.13889
5.5	1.83	$\frac{11}{72}$	0.15278
6.	2.	$\frac{1}{6}$	0.16667

The statical resistance of a thin plate, floating vertically, to lateral motion, is at its centre of pressure, not at its centre of gravity. But there is less practical error in calculating by means of the latter, for several reasons; one being that, when lateral motion has once begun, the water is heaped up in front of the plate, while a hollow is formed behind it. This creates a resistance at the surface which more than compensates for the increased pressure of greater depths. In rapid motion the centre of lateral resistance is found in practice to be considerably above the centre of gravity of the longitudinal section, instead of below it, as is the centre of hydrostatic pressure.

But the centre of lateral resistance of a ship with a full bow and water-line is shifted forward from the moment she has speed, because the resistance on the lee bow is greater than on the weather bow, and because the resistance to a bow in motion is much greater than to the stern. The leeward motion also makes the resistance fall more directly on the bow than on the stern; and hence such vessels, as they increase their speed, experience increasing pressure on the bow as they heel over, thus driving it up into the wind and allowing the stern to drift to leeward.

This disturbance in balance of the lateral resistance of the body has to be met in two ways. The ship has to be trimmed by the stern, which helps to bring back the centre of lateral resistance to the middle. Or it may be met by carrying more sail forward to counteract this effect.

The shifting of the centre of effort of all the sails forward is the mode of correcting this disturbance most employed by naval architects; but as it is not possible to make this adjustment absolute beforehand, each form of ship has its own peculiarity in this respect. One ship will balance her sail with its centre exactly on the middle of the load water-line, another will carry it one-tenth of her length forward of the middle. As a general rule, any vessel having her bow water-lines *convex* may be expected to carry her balance point of ship to balance point of sail—whether going free or on the wind—*one-twentieth* part of her length before the middle, reckoned on the water-line and nearly on an even keel. If the centre of the longitudinal vertical plane be made out of the middle of the length, the centre of effort must follow it.

CHAPTER XIX.

OF THE PROPORTION, BALANCE, DIVISION AND DISTRIBUTION OF SAIL.

A FINE, fast frigate in a ten-knot breeze can carry 36 square feet of sail for each square foot of area of midship section, and be the better for it; if she carried more, she might be pressed over so much as to go slower; hence it has been common to provide a sail area of 36 square feet of canvas for one square foot of midship section.* This proportion can be considerably exceeded by yachts and despatch vessels, even up to 100 square feet; but such vessels are mere sailing phenomena. Nevertheless, for light winds all vessels carry a great quantity of light sail beyond their proportion of regular working sail.

If a sail area is assumed in the proportion of 36 square feet to one square foot of midship section, it is merely saying how much canvas the ship should have in order to drive her. Whether she will be able to stand up under it, and whether under it she will prove leewardly or weatherly, are other questions—questions of stability and balance of sail. All ships tend, under a side wind, to drift to leeward; the only preventive to this being the extent of the immersed longitudinal section, which offers resistance throughout the whole of the length and depth of the ship in the water. The dimensions and shape of this section determine the arrangement and balance of the sail, while a ship should be sufficiently weatherly to carry an area of sail, fore and aft, not less than *six* times the area of this under-water longitudinal section.

As a first step to the consideration of the distribution and balance of sail, draw this section of the vessel under its proper water-line, and copy it by drawing above it a similar section six times as high;

* This proportion refers to "*plain sail*" only, and does not include "*studding sails*," etc.

this call the equivalent-sail area, since it shows, without regard to the kind of vessel, the quantity and disposition of sail which she may carry, and, in short, is what the sails might be, or would be, if she could conveniently carry them all in one.

Indeed, a vessel with one sail is perhaps more effective than with any other number; but the larger the vessel, the more must her sails be subdivided for convenience of handling. There is also a limit to the size at which sails can be made strong enough and stretched flat.

If the vessel were so small that she could carry the whole in one sail, she would be what is commonly termed "a lugger," and the sail "a lug sail." It is to be remarked that the centre of effort of the wind on this sail will be precisely over the centre of resistance of the longitudinal section in the water, and so there will be a perfect balance of sail.

If the vessel be too large to enable the sail to be carried in one, it may be carried in two, without much alteration in shape, and such a vessel will be the common lugger with two masts.

In like manner the sail may be divided into three, and hung on three masts; then the vessel will be a three-masted lugger.

Thus it is plain that this equivalent sail may be obtained indifferently by one, two or three sails, on one, two or three masts, as a matter of convenience merely, and that perfect freedom to make any decision as to distribution is given, provided only that the place and size of the sail, and therefore the balance, are maintained.

In light winds it may be desirable to carry additional sail. All that it is necessary to observe is, that the additional sails be so placed and proportioned as not to disturb the original balance.

By means of the *bowsprit*, the sail may be carried forward until it ends in a point, taking care, however, to extend the sail backward also sufficiently far to offset the addition in front, otherwise the wind will tend to make the vessel sheer round, and the balance will be destroyed. The whole sail will thus become one large triangle. This form is extremely convenient for vessels carrying fore-and-aft sail; but these additional sails fore and aft may be, and indeed are, mere patches, to be used simply as balancing or directing sails, to steady the vessel, without any regard to their propelling power. Such a triangular sail is sometimes carried by a single mast and sometimes divided, in the same manner as lug sails; and it is curious to observe

how differently the whims of sailors may be indulged as to the mode of supporting and carrying these sails—the single sail being equally well carried by an upright mast in the centre of the vessel, by a mast in the bow raking violently aft, and by a mast aft raking as extremely forward, the one condition being fulfilled of leaving the balance of sail unchanged.

As all triangles on the *same base,* having the *same height,* have the *same area,* when once a triangular area of sail* is obtained, it may be changed in shape at pleasure, provided the same height is maintained. It is to be observed, however, that, as the shape of the triangle is changed, the place of effort of the sail is shifted with it. For instance, two triangular sails may have equal areas, but their centres of effort may be in different lines perpendicular to the base, owing to their change of shape.

The balance of sail will be destroyed if, in dividing the sail area, care is not taken to see that, in any new distribution made, the place of the centre of effort is not shifted by that distribution. Not only must the portions cut off from one part of the sail area be supplied in quantity by another, but care must be taken that in their new positions the new parts do not gain or lose power of balance—power of balance being effectual distance. The designer must therefore know how to calculate the exact effect of sails placed at different distances.

To calculate the balance of sail, there are two simple and convenient principles.

A triangular sail has its centre of effort in the line which joins any of its corners to the middle of the opposite side, and is nearer to the side than the corner in the proportion of 1 to 2; so that, by dividing the line into three equal parts, and marking the division which lies nearest the side, you mark the centre of effort of the sail; or it may be found by drawing lines from two corners to the middle point of the opposite sides; where these lines intersect is the centre of effort.

Now it fortunately happens that the shapes of all sails, if not triangles, can be divided into triangles merely by drawing a line through two opposite corners; each part of the sail can thus have its centre of effort separately found.

* Usually known as the "equivalent triangle."

Having thus found the centres of effort of all the sails, or of their separate parts, the next question in order is: How find the joint effort or effect of any pair, or any number of triangular sails, or parts of sails? This is done by the principle of balance; for, in order that two equal sails may balance, they must be at equal distances from the point round which they are *intended* to balance, otherwise the one at the greatest will sway the other; hence equal sails will only balance at equal distances. The equal distances are to be reckoned from the centres of gravity of the respective sails; if, therefore, there are only two equal sails to the vessel, the balance is easy, for it is only necessary to place their centres equi-distant from the balance point in the ship, and the sails will balance. The joint centre of effort of two equal sails therefore lies in the line of, and half-way between, their respective centres of effort.

But it may be a pair of unequal sails, and unequal in any proportion, say 2 to 3. The way to balance them is to give the small sail the longer end of the balance, and to give the longer end the same preponderance in length over the shorter that the larger sail has over the smaller; thus the longer distance, combined with the smaller area of sail, balances the larger area combined with the shorter distance. To see that they are equal, it is only necessary to multiply the areas by their respective distances from the centre: when these products are equal the balance sought for is obtained.

Suppose, on this principle, it is required to find the centre of effort of a sail composed of two triangular parts. Find the centre of effort of each part (by the method before given), join these centres by a line, divide this whole line into as many equal parts as there are square *fathoms** of area in the whole sail, give to the lesser triangle a greater number of these parts and to the greater triangle a less number, in the inverse proportion of the areas; the point of division is the joint centre of effort of the sail.

If now there were a number of sails, some on one side and some on the other of an intended balance point, and the question were asked, whether they balance, it would be necessary to multiply the areas of all the sails by their distance from the balance point; and if the sum of the products on the one side were equal to the sum of the pro-

* Square yards or square feet may also be used, but the number of divisions might be inconvenient.

ducts on the other side, there would be a balance. To obtain a balance, therefore, it is only necessary to contrive that the sums of the products of the sail areas on opposite sides by their distances from the balance points (or their *moments*) shall be equal.

It is plain, then, that to bring about a balance where it does not exist, it is necessary either to substitute a larger sail on the wanting side for a smaller one, or to shift the place of sail nearer to or farther away from the centre as required. A ship whose sails are ill balanced may have the defect corrected in practice by setting different quantities of forward or after sail, or the defect may be rectified on a larger scale by shifting the place of the masts, or in a smaller degree by causing a mast to rake more or less forward or aft. Where these remedies may be inconvenient or impossible, the *centre of resistance* of the *body* of the *ship* may be shifted toward the centre of effort of the sail by trimming the vessel a little more forward or aft, as it is plain that *trimming by the stern* will bring it *aft*, and *trimming by the head* will bring it *forward*.

It is now necessary to establish proportions, according to which the masts and sails of a ship may be divided and distributed. Take for this purpose a vessel with *three* masts, and suppose her to be of the "wave" form, to be on an *even keel*, her length to be divided into *ten* equal parts, and her *bowsprit* to extend so as to bring the centre of the *jib* 5.41 of such tenth parts beyond the *stem*, the extremity of the *spanker* being one-tenth part beyond the *stern*. For the distribution of sail make the following division:

Divide the sail area into 24 equal parts: 7.071 of these are for the *foremast:* 10 for the *mainmast;* 1.65 for the *spanker;* 3.35 for the other sails on the *mizzen-mast;* and the remainder, or 1.929, for the *jib*.

The place of the mizzen-mast is *one-tenth* from the stern, of the foremast *two-tenths* from the bow, and of the mainmast *three-tenths* from the mizzen-mast, or *one-tenth* from the middle, leaving *four-tenths* between the fore and main masts.

Reckoning from the centre of lateral resistance of the vessel, which, on an even keel, is the middle of her length, we have the following arrangements:

Sail.	Quantities.	Effective Distances.		Total Effects or Efforts.	
Spanker	1.65	× 5.	=	8.25	
Mizzen	3.35	× 4.	=	13.40	
Main	10.	× 1.	=	10.	
				31.65	*after* moments.
Fore	7.071	× 3.	=	21.213	
Jib	1.929	× 5.41	=	10.436	
Total	24.			31.649	*fore* moments.

The explanation of the above is simple; the five parts which form the sails on the mizzen consist of 3.35 of the square or upper sails, and the other 1.65 of the spanker, which spanker has its centre of effort one division farther aft than the upper sails: the parts which form the upper sails are therefore multiplied by 4, and give an effect of 13.40; while the parts which form the spanker act at a distance of 5, and give an effect of 8.25.

The ten parts which form the sail area of the mainmast are only at one division from the centre, and give an effect of 10; therefore the total effect of the after sails is represented by 31.65.

In the same manner the moment of the sails forward is found to be as given above, 31.649.

This gives the balance of sail required; and it may be observed that the jib has more absolute effect on this balance than all the sail on the mainmast, while the mizzen, though comparatively small, actually balances the fore. It may also be observed that the jib may be made to balance exactly the upper sails on the mizzen-mast.

It will thus be seen that the total moments of the sails forward are represented by 31.649, the total moments of those abaft by 31.65, and the total number of component parts of sail by 24.

It now remains to be considered how to proportion the various sails on these different masts.*

1st. Of the 5 parts of sail on the mizzen, 1.65 go to the spanker, and the remainder is divided between topsail, top-gallant sail and royal in the following proportion: Mizzen topsail, 1.518; mizzen top-gallant sail, 1.073; and mizzen royal, 0.759.

* These proportions, it must be observed, are for vessels constructed on the "wave" principle, but will answer well for most of the sharp vessels of the day.

2d. Of the 10 parts of sail which go to the mainmast, 3.3 form the course, 3.035 the topsail, 2.147 the top-gallant sail, and 1.518 the royal.

3d. Of the 7.071 which go to the foremast, 2.333 form the course, 2.147 the topsail, 1.518 the top-gallant sail, 1.073 the royal.

Or condensed in tabular form as follows:

Masts.	Sails.					
Mizen....	Spanker..............	1.65 × 5	= 8.25	21.65	31.65
	Topsail....................	1.518 × 4	= 6.072		
	Top-gallant sail........	1.073 × 4	= 4.292		
	Royal......................	0.759 × 4	= 3.036		
Main.....	Course.....................	3.3 × 1	= 3.3	10	
	Topsail....................	3.035 × 1	= 3.035		
	Top-gallant sail........	2.147 × 1	= 2.147		
	Royal......................	1.518 × 1	= 1.518		
Fore......	Course.....................	2.333 × 3	= 6.999	21.213	31.649
	Topsail....................	2.147 × 3	= 6.441		
	Top-gallant sail........	1.518 × 3	= 4.554		
	Royal......................	1.073 × 3	= 3.219		
	Jib*......................	1.929 × 5.41	= 10.436		

But there is a third question to solve, for though the proportion of sail on each mast and the proportion of area of each sail have been obtained, there remains to be found the proportionate dimensions of the masts, which may enable them to carry their respective sails.

In a three-masted ship it is necessary, both for symmetry of appearance and for balance of sail, that the proportion of sail on each mast should be tolerably similar, and that the sizes of masts and spars should bear a due proportion to each other throughout.

The following proportion of sails will accomplish all this. Assuming that each mast has four sails, all similar, then from the proportion before given, namely:

	Mizzen.	Fore.	Main.
Areas of sail....................................	5	7.071	10
Being in the proportion of.....................	1	1.4142	2

In order to make up this proportion it is only necessary that all the sails on the three masts should be in, as nearly as possible, the following proportion:

5 7.071 10

* The term "jib" *may* be used in the sense of *all the sails* on the *head-booms.*

The sails on all the masts will have the proportion required—

1	1.4142	2

For example, when the cross-jack yard has for its breadth of sail 50 feet, then the fore yard should have 70.71 feet, and the main yard 100 feet, or in that proportion.

The corresponding topsail yards should be in the same proportion, namely:

	Mizzen.	Fore.	Main.
Topsail yard	35.35	50	70.71
Top-gallant yards	25	35.35	50
Royal yards	17.67	25	35.35

It is obvious, also, that the lengths of those parts of the masts and spars which carry sail should bear to one another the similar ratio of

	Mizzen.	Fore.	Main.
	5	7.071	10
Or	1	1.4142	2

With these general proportions in view, proceed to complete the arrangement of sail on a given ship, say of 550 tons burden, whose length on the water-line is 150 feet, and draft on an even keel 16 feet 8 inches. Taking six times the draft of water, or 100 feet, this gives the height of the equivalent sail area 100 feet, which, by a length of 150 feet, gives a total sail area of

$$150 \times 100 = 15{,}000 \text{ feet area.}$$

First—to place the masts, divide the length of water-line into 10 equal parts:

Distance of the mizzen-mast from aft	= .1 of 150 =	15 feet.
" " foremast from forward	= .2 of 150 =	30 "
" " mainmast from mizzen	= .3 of 150 =	45 "
" " mainmast from foremast	= .4 of 150 =	60 "
		150 "

Second—to proportion the sail area on each mast:

Mizzen, five-twenty-fourths of 15,000	= 5	× 625	= 3125.
Fore	= 7.071	× 625	= 4419.375
Main	= 10	× 625	= 6250.
Jib	= 1.929	× 625	= 1205.625
			15000.

8

Third. To proportion the sails on each mast:

Mast	Sail			Mast total	Total
Mizen....	Spanker	1.65 × 625 =	1031.25	3125.00	15,000
	Topsail	1.518 × 625 =	948.75		
	Top-gallant sail.....	1.073 × 625 =	670.625		
	Royal	0.759 × 625 =	474.375		
Fore......	Course	2.333 × 625 =	1458.125	4419.375	
	Topsail	2.147 × 625 =	1341.875		
	Top-gallant sail....	1.518 × 625 =	948.75		
	Royal	1.073 × 625 =	670.625		
Main	Course	3.3 × 625 =	2062.5	6250.00	
	Topsail	3.035 × 625 =	1896.875		
	Top-gallant sail....	2.147 × 625 =	1341.875		
	Royal	1.518 × 625 =	948.75		
	Jib..................................	=	1205.625		

Or in other words—

	Spanker.	Fore course.	Main course.
	1.65	2.333	3.3
Or in the proportion of................	1.	1.4142	2.

	Mizzen Topsail.	Fore Topsail.	Main Topsail.
	1.518	2.147	3.035
Or in the proportion of................	1.	1.4142	2.

	Mizzen Top-gallant sail.	Fore Top-gallant sail.	Main Top-gallant sail.
	1.073	1.518	2.147
Or in the proportion of................	1.	1.4142	2.

	Mizzen Royal.	Fore Royal.	Main Royal.
	0.759	1.073	1.518
Or in the proportion of................	1.	1.4142	2.

Again:

	Topsail.	Top-gallant sail.	Royal.
Mizzen................................	1.518	1.073	0.759
Or in the proportion of................	2.	1.4142	1.
Main	3.035	2.147	1.518
Or in the proportion of................	2.	1.4142	1.
Fore......................................	2.147	1.518	1.073
Or in the proportion of................	2.	1.4142	1.

Now to get the length of the yards: The lower yards are at once found by taking the *square root* of *twice* the area of the *courses*, and for the mizzen-mast, as the area of the spanker is the same as that of a course,* if there had been one for the cross-jack yard, the square root of twice the area of the spanker must be taken.

* This means "cross-jack," a sail seldom used except in the merchant service.

From this is found .

The length of the Main yard.........	64.23, or in the proportion of			1
"	" *Fore yard*..........	54.	"	"	0.8409
"	" *Cross-jack yard*....	45.41	"	"	0.7071

These proportions give the length of yards and *hoist* of sail; for multiplying the length of the main yard by 0.8409, we get the length of the *fore yard* and *main topsail yard;* by multiplying the length of the fore yard or main topsail yard by 0.8409, we get the length of the *cross-jack yard, fore topsail yard* and *main top-gallant yard,* and so on, always excluding "*yard arms.*" These same proportions answer for the hoist of sail; or in other words, *half* the length of the *main yard* is the *hoist* of the *main topsail; half* the length of the *main topsail yard* is the *hoist* of the *main top-gallant sail; half* the length of the *main top-gallant yard* is the *hoist* of the *main royal.*

It will thus be seen that by this arrangement there is one yard of the length of the main yard, two yards of the length of the main topsail yard, three yards of the length of the main top-gallant yard, three yards of the length of the main royal yard, two yards of the length of the fore royal yard, and one yard of the length of the mizzen royal yard.* Working the above quantities out for the vessel whose areas of sail have been calculated, there results for the length of

Main.	Fore.	Mizzen.
Main yard......... = 64.23	Fore yard......... = 54.	Cross-jack yard.. = 45.41
Topsail yard...... = 54.	Topsail yard...... = 45.41	Topsail yard...... = 38.18
Top-gallant yard = 45.41	Top-gallant yard = 38.18	Top-gallant yard = 32.41
Royal yard........ = 38.18	Royal yard....... = 32.41	Royal yard....... = 27.26

And when, with these figures, the areas of the different upper sails are calculated, it will be seen that the quantities found in this manner, and the quantities found in the first manner, agree with great precision.

It is plain that with the foregoing arrangement *a perfect balance* is obtained; that is, the *centre of effort of sail* falls *exactly* in the same perpendicular with the *centre of lateral resistance.* Now in some ships it is preferable to have the centre of effort some distance for-

* It will be observed by naval officers that these proportions are somewhat different from those formerly in use.

ward of the centre of lateral resistance, and this is easily accomplished by means of the jib.

The centre of the jib in the foregoing calculations was situated at 5.41 from the centre or middle division. Now, by merely shifting its centre to six divisions from this middle, which in the vessel of 150 feet length, would be 90 feet, the centre of effort would be brought forward 5 feet. This may seem difficult to do, as the masts are fixed and the *jib-stay* cannot be shifted; it therefore remains to alter the shape of the jib, which is done in the following manner:

Erect a perpendicular line on the sixth division from the middle of the water-line, then on this perpendicular the centre of effort of the jib *must* be situated. Lengthen this perpendicular until it meets the jib-stay, then lay off from this intersection equal distances, up and down along the stay, as far as convenient; the sum of these two distances should form the length of the luff of the jib. The area of the jib being given, divide the area by one-half the luff, and lay off the quotient from the jib-stay along the perpendicular line; join the point thus found with the two extremities of the luff, and there is obtained a shape of jib of the given area, and with its centre falling exactly at the sixth division from the middle, or one-tenth of the length beyond the stem. But this degree of accuracy is much greater than is required for practice; and it is necessary to guard against the attempt to fix these points in the design too closely before taking into consideration a multitude of practical points of convenience, use and taste, which go to regulate the dimensions of sails. In the first place, it must never be forgotten that nearly all ships carry weather-helm, and that this proportion of weather-helm generally increases with the wind.

It is to be observed that the design of the sails having been made in proper balance, any change made to correct defects in the form of the body should not be allowed to derange either the proportions or places of the sails; but for this purpose the *whole* of the sails should be removed to their new place, and not shifted with respect to each other, unless due regard be had to maintaining their balance.

Another point for consideration is, that if masts are made to rake instead of standing upright, it must not be forgotten that rake may shift the relative distance of the sails.

A further point is, that the convenience of the ship herself may interfere with the disposition of sails. A high forecastle will shorten the drop of the foresail, and a poop may seriously interfere with the spanker. These are points which must on no account be neglected.

Perhaps the most important point that can be kept in view in the study of the balance of sail, balance of body, placing of masts, proportion of spars and subdivision of sails, is this, that in all circumstances the ship should be able to carry the greatest quantity of sail with the least possible action of rudder. In a perfect "wave" form, perfectly balanced, this has been done, and in a fast-sailing clipper it is vital. In such a vessel the whole of the sails mentioned would be carried, whether the wind was light or fresh, without retarding the ship by the action of the helm. When it came on to blow hard, it would only be necessary to furl the three top-gallant sails, and the rest of the sails would remain in perfect balance; blowing harder, the topsails might all be reefed and a balance still maintained; blowing a gale, the spanker, jib, foresail and mainsail might be taken in, and yet a perfect balance exist under close-reefed topsails and storm jib. Thus, in a ship built on the "wave" theory, even in heavy weather the commander would find his ship handy, fast and under perfect command; but if the vessel were not a "wave" vessel, the following changes would take place: As soon as it came on to blow fresh, the spanker, which is a most powerful sail, would be found to cause an excessive degree of weather-helm, and would have to be taken in, but that would spoil the balance, and the jib would follow the spanker, giving place to the topmast staysail, which would at once reduce very seriously the way of the vessel, and it would be want of balance and not stress of weather which did it. If it came on to blow hard, it would soon be necessary to take all sail off the mizzen, except perhaps a small storm sail for lying-to.

In ships of this class nothing but experience will tell under what sails the ship will balance, and what she will not carry; but one thing is certain, that in the light winds and strong ones the balance will be entirely different, which is not the case in the "wave"-formed ships.

TABLE IX. (Summary.)

Areas and Powers of Sails with four Yards on each Mast.

Six times the area of the immersed longitudinal section is taken as the standard sail area of the ship, of which, the

$$\left.\begin{array}{lll} \text{Area of all the square sails on Mainmast....} = \frac{10}{24} & \text{of the whole area} \\ \text{" " " Foremast.....} = \frac{7.071}{24} & \text{" "} \\ \text{" " " Mizzen-mast} = \frac{3.35}{24} & \text{" "} \\ \text{Area of the Spanker......} = \frac{1.65}{24} & \text{" "} \\ \text{" Jib............} = \frac{1.929}{24} & \text{" "} \end{array}\right\} \frac{24}{24}$$

The *powers* of these quantities are—

For Main area.. 1.
" Fore area.. 3.
" Mizzen area.. 4.
" Spanker area.. 5.
" Jib area.. 5.41

Or, using decimals, the

$$\left.\begin{array}{lll} \text{Area of all the square sails on Mainmast....} = 0.4167 & \text{of the whole area} \\ \text{" " " Foremast....} = 0.2946 & \text{" "} \\ \text{" " " Mizzen-mast} = 0.1396 & \text{" "} \\ \text{Area of the Spanker......} = 0.0687 & \text{" "} \\ \text{" Jib...........} = 0.0804 & \text{" "} \end{array}\right\} 1.$$

The *momenta* from the middle of the water-line are—

Spanker.	Mizzen.	Main.	Fore.	Jib.
1.65	3.35	10	7.071	1.929
×	×	×	×	×
5	4	1	3	5.41
=	=	=	=	=
8.25	13.40	10	21.213	10.436
		13.40		
		8.25	10.436	
	After momenta	31.65 =	31.649	*Fore* momenta.

TABLE IX.—*Continued.*

The area of the Main Course	= 0.1375	of the whole area		
" " " Topsail	= 0.1265	" "		
" " " Top-gallant sail	= 0.0895	" "		
" " " Royal	= 0.0632	" "		
" " Fore Course	= 0.0972	" "		
" " " Topsail	= 0.0895	" "		
" " " Top-gallant sail	= 0.0632	" "		
" " " Royal	= 0.0447	" "	= 1	
" " Mizzen Topsail	= 0.0632	" "		
" " " Top-gallant sail	= 0.0447	" "		
" " " Royal	= 0.0317	" "		
" " Spanker	= 0.0687	" "		
" " Jib	= 0.0804	" "		

Place of the Masts.

The length of the ship on the *load water-line* from the *after* part of the stern-post to *forward* part of the stem is divided into ten equal parts:

The Mizzen-mast is placed at one-tenth from the stern-post.
" Main " " four-tenths " "
" Fore " " eight-tenths " "

Co-efficients of Proportions of Spars and Sails.

With 4 yards on each mast the

Course	= 0.33	of whole sail area of mast.	The area of the Course being given, the length of the yard is equal to $\sqrt{2 \times 0.1375 \times A} = \sqrt{0.2750 \times \text{area of ship's sails}}$.
Topsail	= 0.3035	" " "	
Top-gallant sail	= 0.2147	" " "	
Royal	= 0.1518	" " "	

TABLE X.

Classification of Spars and Sails.

(For ships with four yards on each mast.)

Class.	Yards.	Courses.	Diminished Sails.	Spankers.	Jibs.	Ship's Sail Area.
9	118.921	7071.07	6508.5	3535.53	4133.36	51425.95
8	100.000	5000.00	4602.2	2500.00	2922.73	36363.63
7	84.089	3535.53	3254.25	1767.77	2066.68	25712.98
6	70.711	2500.00	2301.10	1250.00	1461.36	18181.82
5	59.461	1767.77	1627.12	883.88	1033.34	12856.49
4	50.000	1250.00	1150.55	625.00	730.68	9090.91
3	42.045	883.88	813.66	441.94	516.67	6428.24
2	35.355	625.00	573.28	312.50	365.34	4545.45
1	29.730	441.94	406.83	220.97	258.34	3214.12

GEOMETRICAL CONSTRUCTION OF SAILS.

I. Square Sails (Fig. 18).—*Given the foot,* BB, *the depth,* AC, *and the area of a square sail, to construct its figure.*

Divide the area by half the breadth at the foot, lay off the quotient, AD, upward from the foot on the upright centre line. Join CB, CB, and parallel to those lines, draw DE, DE. Through C draw a straight line parallel to BB, cutting the two oblique lines from D in EE; join EB, EB; then EE will be the head of the sail, and EB, EB, its leeches.

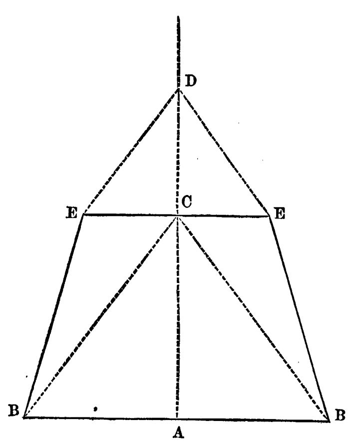

Fig. 18.

II. TRIANGULAR SAILS (FIG. 19).—*Given the foot,* AB, *the direction of one leech,* AC, *and the area of a triangular sail, to construct its figure.*

Divide the area by half the foot, and set up the quotient as a perpendicular, AD to AB. Through D, draw DE parallel to AB, cutting AC in E; join EB; then ABE is the required figure.

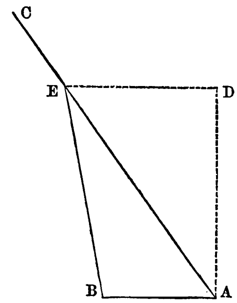

FIG. 19.

III. QUADRANGULAR FORE-AND-AFT SAILS (Fig. 20).—*Given the foot,* AB, *the luff,* AC, *the direction,* CH, *of the head, and the area of a quadrangular sail, to construct its figure.*

Divide the area by half the foot, and set up the quotient as a perpendicular, AD to AB. Through D draw DE, cutting AC produced in E. Join CB, and parallel to it, through E, draw EK, cutting CH in K. Join KB. Then ABKC will be the required figure.

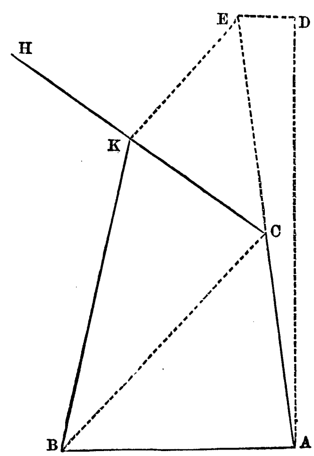

FIG. 20.

When the sail draft of a vessel has been approximately prepared, it may be necessary for verification to calculate from the drawing the areas of the several sails, for which the following rules are useful.

TO FIND THE AREA.

IV. *Of a Square Sail.*—Multiply the depth by the half sum of the breadths at the head and foot.

V. *Of a Triangular Fore-and-aft Sail.*—Multiply *any* side by one-half its perpendicular distance from the opposite corner.

VI. *Of a Four-sided Fore-and-aft Sail.*—Multiply either diagonal by the half sum of its perpendicular distances from the opposite corners.

The *centre** can then be found, as follows:

* That is, the centre of gravity or centre of effort.

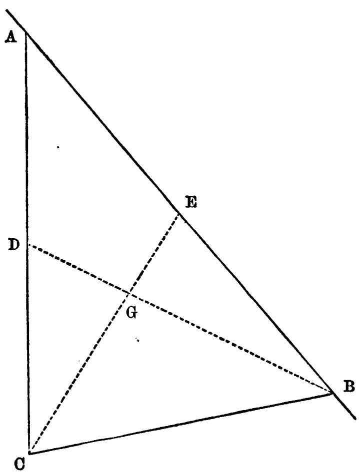

FIG. 21.

VII. TRIANGULAR SAILS (Fig. 21).—From any two of the corners draw straight lines to the centres of the opposite sides; the intersection, G, of those lines will be the centre of the sail; or the centre may be found by drawing a straight line from any corner to the middle of the opposite side, and cutting off one-third of that line, beginning at the side, as DG or EG.

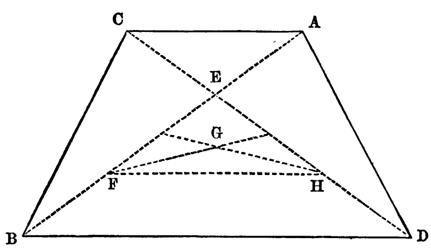

FIG. 22.

VIII. FOUR-SIDED SAILS.—*Case First* (Fig. 22).—Draw the diagonals AB and CD, cutting each other in E; make BF = AE, and DH = CE; then by Rule VII. find the centre G of the triangle EFH, which will be the centre required.

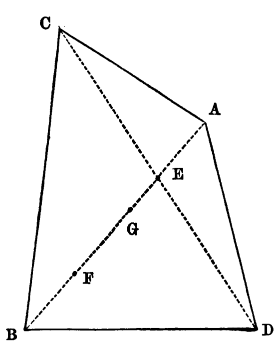

FIG. 23.

IX. FOUR-SIDED SAILS.—*Case Second* (Fig. 23).—When E happens to bisect one of the diagonals, as CD, so that Rule VIII. fails, make BF in the other diagonal = AE, and EG = $\frac{1}{3}$ EF; G will be the centre required.

When a sail is bounded by slightly curved lines, an *approximation* near enough for all practical purposes may be made by drawing straight boundaries, so as to enclose, as nearly as can be judged by the eye, an equal area having the same centre.

The *centre of effort*, or common centre of *all* the sails, may be found as follows:

X. Multiply the *area* of each sail by the *height* of its *centre* above any convenient horizontal line (say the load water-line), divide the *sum* of the products by the total area of sail; the quotient will be the *height* of the centre of effort of all the sails above the same horizontal (load water) line.

XI. Multiply the *area* of each sail by the *horizontal distance* of its *centre* from any convenient *vertical* line (such as a line drawn vertically through the middle of the load water-line, or through the *centre of lateral resistance*); distinguish the products into *forward* and *after*, according as the centres of the sails lie before or abaft the vertical line; take the *sums* of the forward and after products separately and the *difference* of those sums; divide that difference by the *total area* of sail; the quotient will be the *horizontal distance* of the centre of effort from the *vertical* line, and will lie before or abaft that line, according as the forward or after products are in all the greater.

XII. The *moment of sail* is then to be computed by multiplying the area of sail by the height of the centre of effort above the centre of the immersed longitudinal section (centre of lateral resistance); and by comparing the area and moment as now calculated in detail with the previous estimate of those quantities obtained, it will be ascertained whether the design for the sails on the sail draft requires modification in order to adapt it properly to the stability of the vessel.

XIII. The sails are then to be distinguished into *head sail* and *after sail;* and the *centre* of the head sail and *centre* of the after sail are to be found separately, in the same manner with the centre of effort—the proportion which the horizontal distance between those two centres bears to the length of the line of flotation (load water-line) is a measure of the *handiness* of the vessel when manœuvring under sail, and ranges from 0.6 to 0.7 in good examples.

The *areas* of head sail and of after sail are of course to each other *inversely* as the distances of their respective centres from the centre of effort. Their relative proportion varies very much in the smaller class of vessels; in ships, however, it is more nearly uniform, the area of after sail being greater than the area of head sail in a ratio which ranges from 3 : 2 to 5 : 3. The greater area of after sail is

advantageous, as counteracting the tendency to check the ship's headway, when the head sail or part of it is taken aback during the operation of *tacking.*

TABLE XI.

BALANCE OF SAIL.

Four Square Sails on each Mast, and Jib to balance.

1.

	Mizzen	Main.	Fore.	Jib.
Areas	$\frac{5}{24}$	$\frac{10}{24}$	$\frac{7.071}{24}$	$\frac{1.929}{24}$
	×	×	×	×
Leverage	4	1	3	4.5552
	=	=	=	=
Horizontal moments	20	10	21.213	8.7869
		20	8.7869	
	After moments	30 =	29.9999	Fore moments,

or the centre of effort falls exactly in the *middle* of the load water-line.

	Mizzen.	Main.	Fore.	Jib.
Areas	$\frac{5}{24}$	$\frac{10}{24}$	$\frac{7.071}{24}$	$\frac{1.929}{24}$
	×	×	×	×
Leverage	1.14 a	1.6168 a	1.332	0.8409 a
	=	=	=	=
Vertical moments	5.7 a	16.168 a	10.418 a	1.662 a
		10.418 a		
		1.662 a		
		5.7 a		
		33.908 a	equal to the sum of moments.	

The sum of the moments divided by the total area, or 24, gives 1.412 a, in which a represents the height of the main course.

Under all Plain Sail.

2.

	Spanker.	Mizzen.	Main.	Fore.	Jib.
Areas	$\frac{1.65}{24}$	$\frac{3.35}{24}$	$\frac{10}{24}$	$\frac{7.071}{24}$	$\frac{1.929}{24}$
	×	×	×	×	×
Leverage	5	4	1	3	5.41
	=	=	=	=	=
Horizontal moments	8.25	13.40	10	21.213	10.436
			13.40	10.436	
			8.25		
		After moments	31.65 =	31.649	Fore moments,

or the centre of effort falls in the *middle* of the load water-line.

Under all Plain Sail (continued).

	Spanker.	Mizzen.	Main.	Fore.	Jib.
Areas..................	$\frac{1.65}{24}$	$\frac{3.35}{24}$	$\frac{10}{24}$	$\frac{7.071}{24}$	$\frac{1.929}{24}$
	$\times$	$\times$	$\times$	$\times$	$\times$
Leverage..............	0.3535 a	1.5386	1.6168 $\times$ a	1.332 $\times$ a	0.8409 $\times$ a
	=	=	=	=	=
Vertical moments..	0.5833 a	5.1543 a	16.168 $\times$ a	10.418 a	1.622 a

The sum of these vertical moments = 33.9 $\times$ a. This, divided by 24, or the whole area, gives for the distance of the centre above the bottom of sail 1.41 $\times$ a, in which a is the height of main course as before.

In the same way—

Without Royals.

3.

After moments, 27.096 = 27.093 fore moments, or the centre of effort falls in the *middle* of the load water-line; and

Sum of vertical moments, 24.317, which, divided by 20.40, or the sail area, gives for distance of centre above bottom of sail, 1.21 $\times$ a.

Under Topsails, Courses, Jib and Spanker.

4.

After moments 20.657 = 20.656 fore moments; or the centre of effort falls in the middle of the load water-line; and

Sum of vertical moments = 13.0933 $\times$ a, which, divided by 15.32, or the area, gives for the distance of the centre above the bottom of the sail, 0.85 $\times$ a.

Under Topsails only.

5.

	Mizzen Topsail.	Main Topsail.	Fore Topsail.	Storm Jib.
Areas......................	$\frac{1.518}{24}$	$\frac{3.035}{24}$	$\frac{2.147}{24}$	$\frac{0.4927}{24}$
	$\times$	$\times$	$\times$	$\times$
Leverage.................	4	1	3	5.41
	=	=	=	=
Horizontal moments..	6.072	3.035	6.441	2.66
		6.072	2.66	
	After moments	9.10 =	9.101 Fore moments,	

or the centre of effort falls in the *middle* of the load water-line.

	Mizzen Topsail.	Main Topsail.	Fore Topsail.	Storm Jib.
Areas......................	$\frac{1.518}{24}$	$\frac{3.035}{24}$	$\frac{2.147}{24}$	$\frac{0.4927}{24}$
Leverage................	1.1919 $\times$ a	1.4848 $\times$ a	1.3257 $\times$ a	0.8409
	=	=	=	=
Moments (vertical)...	1.81	4.51	2.85	0.41

The sum of these vertical moments $= 9.58 \times a$. This divided by 7.19, or the area, gives for the distance of the centre above the bottom of the sail, 1.33 a.*

It is to be noticed, in using the tables, that the centre of the sails is taken as being in the line of the mast, and all the sails are supposed to be braced round in a line parallel to the keel.† Also, that where length of yard is spoken of, only that part of the yard *covered by the spread of sail is included.* Thirdly, that the length of the ship is taken on the load water-line and the middle of the ship at the middle of that line. But care must be taken that, when the centre of resistance of the ship is shifted aft by trim, or is shifted forward by the resistance of the water to the bow when under way, the centre of effort shall also be shifted so as to maintain the balance. Ships with full bows have their centre of lateral resistance shifted forward from the middle as much as *one-twentieth* of the length of the load water-line. This shifted point must then be considered as the middle point, and the distance from this shifted point to the forward end of the water-line as half the length; and the distribution of sail must be made on this new middle and reduced length, instead of on the true middle and true length of load water-line.

When a given sail area is to be carried on a ship, Table XII. shows the dimensions and distribution of *balancing sails,* as described in this chapter, and enables the constructor to determine the dimensions of spars and sails for the given amount of sail area by simple inspection.

When the ship is not of the "wave" form, but such as to shift the centre of resistance forward from the *true* middle when going fast, then this shifted centre *must* be taken as the *true* middle, and the masts and sails distributed on both sides, as if it were the true middle; and the ten divisions of length must be taken as extending, one-half from the bow to this shifted middle, and the other half to an equal distance abaft the shifted middle.

* In all the foregoing calculations, a is the height of the main course. Of a single topsail the centre of effort lies at $\frac{16}{33}$ from its base; of the three upper sails—viz., topsail, top-gallant sail and royal—the centre of effort is situated at $\frac{6}{13}$ from the bottom of the lowest sail; and of all four sails on one mast, the centre of effort is situated at $\frac{5}{11}$ from the bottom of the course.

† The sails being supposed to be flat, like boards.

TABLE XII.

Dimensions and Areas of Sails for a given Sail Area for Vessels Designed on the "Wave" System.

Total Sail Area of Ship.	Length of Main yard.	Main Topsail and Fore yard.	Main Top-gallant, Fore Topsail and Cross-jack yard.	Main Royal, Fore Top-gallant and Mizzen Topsail yard.	Fore Royal and Mizzen Top-gallant yard.	Mizzen Royal yard.	Area of Mainsail.	Area of Foresail.	Area of Main Top-sail.	Area of Main Top-gallant and Fore Topsail.	Area of Main Royal, Fore Top-gallant and Mizzen Top-sail.	Area of Fore Royal and Mizzen Top-gallant Sail.	Area of Mizzen Royal.	Area of Jib.	Area of Spanker.
54,124	122	102.60	86.26	72.54	61.0	51.3	7442	5244	6850	4842	3423	2421	1712	4352	3721
52,364	120	100.91	84.85	71.35	60.0	50.46	7200	5090	6627	4686	3313	2343	1656	4210	3600
48,091	115	96.71	81.32	68.38	57.5	48.36	6613	4679	6088	4304	3043	2152	1521	3866	3307
44,804	111	93.35	78.49	66.00	55.5	46.68	6161	4364	5671	4011	2836	2006	1418	3602	3081
40,091	105	88.30	74.24	62.43	52.5	44.15	5513	3896	5073	3587	2536	1794	1269	3223	2757
34,924	98	82.41	69.30	58.27	49.0	41.21	4802	3430	4420	3126	2210	1563	1105	2808	2401
32,818	95	79.89	67.18	56.49	47.5	39.95	4513	3190	4153	2938	2078	1469	1038	2639	2257
29,455	90	75.68	63.64	53.51	45.0	37.84	4050	2863	3728	2636	1863	1318	932	2368	2025
25,051	83	69.80	58.69	49.35	41.5	34.90	3445	2435	3170	2241	1585	1120	792	2014	1723
23,273	80	67.27	56.57	47.57	40.0	33.64	3200	2262	2945	2083	1473	1041	736	1871	1600
21,560	77	64.75	54.45	45.78	38.5	32.38	2965	2096	2729	1931	1366	965	683	1734	1483
20,455	75	63.07	53.03	44.59	37.5	31.54	2813	1988	2590	1833	1296	917	648	1644	1407
17,818	70	58.86	49.50	41.62	35.0	29.43	2450	1732	2255	1595	1128	797	564	1433	1225
16,324	67	56.34	47.38	39.84	33.5	28.17	2245	1587	2066	1461	1033	730	516	1313	1123
14,895	64	53.82	45 26	38.05	32.0	26.91	2048	1447	1886	1333	942	667	472	1197	1024
13,091	60	50.45	42.43	35.68	30.0	25.23	1800	1272	1657	1172	828	586	414	1052	900
11,815	57	47.93	40.31	33.89	28.5	23.97	1625	1148	1494	1057	747	528	374	950	813
10,215	53	44.57	37.48	31.51	26.5	22.29	1405	992	1292	914	646	457	322	821	703
9,458	51	42.89	36.06	30.32	25.5	21.95	1301	919	1197	847	599	423	299	761	651
8,378	48	40.37	33.94	28.54	24.0	20.18	1152	814	1061	750	530	375	266	673	576
7,040	44	37.01	31.11	26.16	22.0	18.51	968	684	891	630	445	315	223	566	484
5,818	40	33.64	28.28	23.78	20.0	16.82	800	566	736	521	369	260	184	468	400
4,978	37	31.12	26.16	22.00	18.5	15.56	685	484	631	446	315	223	158	400	343
3,960	33	27.76	23.34	19.62	16.5	13.88	545	385	501	354	250	177	125	319	273
3,273	30	25.23	21.21	17.84	15.0	12.67	450	318	414	293	206	146	103	263	225
2,851	28	23.55	19.80	16.65	14.0	11.78	392	277	361	255	181	127	90	229	196

TABLE XIII.*

Force and Velocity of Wind.

Miles an hour.	Pounds per Square foot.	Miles an hour.	Pounds per Square foot.	Miles an hour.	Pounds per Square foot.
10	0.25	34	2.89	49	6.00
12	0.36	36	3.24	50	6.25
14	0.49	38	3.61	51	6.50
16	0.64	40	4.00	52	6.76
18	0.81	41	4.22	53	7.02
20	1.00	42	4.41	54	7.29
22	1.21	43	4.62	55	7.56
24	1.44	44	4.84	56	7.84
26	1.69	45	5.06	57	8.12
28	1.96	46	5.29	58	8.41
30	2.25	47	5.52	59	8.70
32	2.56	48	5.76	60	9.00

TABLE XIV.

Force of the Wind, from 1 lb. to 10 lbs. pressure per Square Foot.

Names.	Pressure in pounds.	Velocity in statute miles.	Names.	Pressure in pounds.	Velocity in statute miles.
Top-gallant breeze..	1.0	13.80	Close-reefed topsails	3.53	23
Fresh top-gallant breeze..............	1.5	17.25	Scudding sails........	5.24	28
Whole topsail breeze	2.0	18.00	Half storm............	7.67	34
Reefed topsails......	2.67	20.00	Whole storm.........	10.66	40

* This table has been verified by direct measurement in motion through the air on a railway.

CHAPTER XX.

OF SYMMETRY, FASHION AND HANDINESS OF SAIL.

HITHERTO the sails have been studied with reference to their effect on the ship, in so far as concerns the work of the naval architect. If they are well proportioned in size to the ship, or well balanced, so as to leave her free in her movements; if they are so proportioned in dimensions that they drive without overpowering her, or can be varied in quantity to any extent without derangement of balance, and always leave her under command of the helm,—then the first requisites of the naval architect are accomplished. But other things are demanded, besides this first essential—their use to the ship. The seaman must be satisfied with the figure, distribution and cut of his sails; besides this, they must suit his convenience and use. They must set well, stand well, draw well, be easily set, easily worked, easily reefed, easily taken in; in short, be conveniently, easily and safely handled. On this point the will of the seaman should rule the design.

The quantity and balance of sail are the business of the naval architect; the symmetry, fashion and cut of the sails are the vocation of the seaman, not of the landsman. The naval architect has now to consider how he shall give the seaman all he wishes in regard to fashion and symmetry, without compromising the other conditions on which the ship is designed. This requires skill, though for this purpose all that has been said about balance of sail and of ship forms an excellent basis on which may be grafted any amount of fashion and of fancy, of fitness and of handiness.

Suppose a full-rigged ship to have been designed, and the place of all the principal sails, their areas and their dimensions, to be laid down on a sail-draft by the rules already given, the question now

raised is, How may the fashion of the sails be altered without disturbing their balance or changing their quantity?

There is manifestly a great variety in fashion for the same area, while for every square sail there arises three main questions:

1st. Taper of sail, or diminution of the head of each sail, compared with the width at the foot.

2d. Proportion of height to width, or spread of sail in proportion to hoist.

3d. Sub-division of sails on a mast.

I. *Diminution of the head of the sails on a given mast.*

The sails on the same mast may all have the same taper, diminishing in one straight line; or they may vary in taper, though it is obvious that whatever reason exists for a certain taper in a given sail will apply equally to that above it. That the sails on all three masts should have the same taper, one and all, seems evident, and there exists a preference for having one proportion for the diminution of the head of the sail running through all the higher sails of the same mast, especially where the subdivisions are numerous, though it is a frequent practice to narrow most the heads of the higher sails.

The argument for diminishing the heads of the sails is that the higher masts and gear are lighter than the lower, and therefore less able to carry heavy and large sails and yards. On the other hand is the argument that the loftier sails are not set in bad weather, but are taken in when it blows hard, so that being fair-weather sails they should be large, or else they are of but little use; and this latter consideration is entitled to considerable weight. The lofty sails should, it is thought, have a wider spread and a smaller proportion of height to width than has been usual hitherto. There is a growing tendency in *fast* vessels to carry *large* and *low* sails, and to obtain greater *spread* of sail with less *hoist.*

Moreover, with the adoption of iron and steel as materials for masts, and wire rope for rigging, sails of great spread and moderate hoist will, it is believed, be more and more used.

Three things must be remembered in considering what diminution of sail may be adopted in any given ship:

1st. That by increasing the spread of the lower sails, and tapering rapidly the upper, the centre of effort of the sails is lowered.

2d. That by narrowing the upper sails they become of less area and of less value.

3d. That in altering the taper it is only necessary to remember that by so much as the alteration adds to one part of the sail area on a given mast, by so much also shall it diminish the area at another part.

Thus any amount of change or diminution may be given to the sails on each mast without changing the balance of sail area on the whole ship.

II. *Proportion of height to width in a square sail.*

It seems that in proportion as ships sail faster and are built finer and longer, the separate sails are made broader and lower, their yards longer and their hoist less, as, by giving squareness to a sail, not only is a larger quantity of low sail carried, but the sails stand flatter and better on a wind. On the other hand, there is this consideration: that yards of great length are costly and heavy—heavy to carry and to work; and that by merely increasing the hoist the same yard may be made to carry much more canvas and do much more work.

This goes in favor of increased hoist, but it loses weight from the fact that a square sail of great height does not stand well on a wind; and that a fast ship will sail faster on a wind with square and low sails than with high and narrow ones.

The fact that yards of great length are heavy to carry and hard to work will therefore be a good argument in favor of narrow and lofty sails for slow ships, short voyages and small crews. On the contrary, in long voyages and with plenty of able seamen, spread being of value, long yards and moderate hoist are preferable.*

The limits of proportion taken are these: When the *hoist* of a square sail is made *equal* to its *spread*, it should be reckoned an *extreme height* of sail. When the *hoist* is *one-half* of the *greatest width*, it would be reckoned a *broad* and *low* sail. They ought not to be lower to avoid waste, because a sail of that height will stand close to the wind; therefore the above may be assumed as a *standard* proportion of height to width.

III. *Sub-division of sails on a mast.*

The proportion of width to height of sail may be considered apart

* Men-of-war may be classed in this category.

from taper or diminution of head; nevertheless a rapid rate of diminution may better suit lofty sails, and a more gradual rate lower sails. But much of the symmetry of a suit of sails depends on keeping some one proportion of height to width throughout the sails on the same mast, as well as on the different masts of the same ship.

In fast ships there is a strong tendency in this direction; and it is believed that as the introduction of iron masts frees the ship-builder from the difficulty of finding spars of sufficient length and strength in the forests, and enables him to make masts of any length in one piece, without break or discontinuity, this is a great encouragement to the adoption of symmetry and uniformity in the proportion and fashion of sail. It seems plain that when some one proportion of height to width has been selected as possessing the requisite qualities in the best practical degree, there can be no sufficient reason for adopting that proportion in one sail on a mast and rejecting it in the others.

Take, therefore, for example's sake, the sails on one mast and divide them so that they may all have one proportion of spread and hoist. That sub-division may be altered in any way found most convenient for working. In men-of-war the topsail is the great working sail of the ship; and being generally of great hoist, may be taken as an extreme proportion. In the double-topsail sailing clipper the same sail is cut into two sails, often of a ridiculously small hoist. These are two extremes between which there should be some medium. It is thought not out of place to repeat here that sub-division of sails is more a matter of *seamanship* than of naval construction—is more, in fact, a question of working a ship than of designing one, as, generally speaking, the sails liked best will be worked best. What the seaman likes will depend not merely on his *experience*, but on the *power* at his disposal to work his ship and on the value that *speed* may have to him. Given—a stable, fine, fleet ship for long voyages, it is thought better to have sails not high, but of great spread. For short voyages, narrow seas, moderate speed and a small ship's company, narrow sails, lofty and easily worked, may be preferred; and in like manner, sails few and large, or many and small, have corresponding advantages or disadvantages.

Hitherto, reference has been made mainly to sails of a *quadrangular* shape or square sails, which are not only the most universal of form and arrangement, but are universally used on the largest scale.

Triangular sails are not less valuable, but are to be reckoned in some sort as subsidiary sails. They take their form almost inevitably from other considerations, to which they are subordinate. Thus, even the jib of a man-of-war, the chief triangular sail, takes its shape and proportion almost exclusively from the angle of the jib-stay, and is decided in shape by the proportion of masts and direction of rigging, which have been determined by precedent considerations.

If there is less scope for choice and design in triangular sails than in square sails, there is this compensating virtue in the former, that they are accommodating enough to take any shape without loss of value. A jib covering a given length of its boom is of the same area, and does not vary with the *steeve*, provided it rise to a given height, measured square off the line of its boom; while, so long as it rises to the same height, its centre of effort will be at the same height taken square from the boom.

There is another point in which a triangular sail differs from a square sail; it draws well independent of its height. So long as a triangular sail is not too wide fore and aft, it will set flat close to the wind, and without the large belly which great height would give a square sail. The chief virtue of triangular sails is this special quality of setting flat and going close to the wind.

Spankers and trysails also have the same advantages as triangular sails of standing well and keeping flat close to the wind, but the gaff has the disadvantage of tending to sway over to leeward, and the head of the sail shakes while the foot stands.

In calculating the balance and distribution of *square*, *triangular* or *fore-and-aft sails*, it is a matter of indifference, what the sort of sail is, as a *fore-and-aft sail* may be substituted at any point for a *square* sail, provided the same area is kept and the balance point or centre of effort in the same place. The sails will balance the ship equally well whether square or fore-and-aft.

But there is this radical difference between fore-and-aft sails and square sails. Fore-and-aft sails *shift* their centres of effort with their trim; they travel in circles round a fixed point, and they carry their centres round with them. Square sails never shift their centres of effort so long as they are set flat, the centres being fixed points on the mast around which they turn.

This shifting of the centre in fore-and-aft sails is of considerable

importance, because it carries the centre of effort farther forward as the ship's course goes off from the wind. It returns when close-hauled, but it must be kept in mind that it is always a little forward of its calculated place, and this is perhaps one of the reasons why, in fore-and-aft-rigged vessels, the centre of effort of the sails requires a smaller shift forward of the middle, in order to meet the shift of the centre of resistance of the body of the vessel as the speed increases. It must always remain a great point in favor of the square-rigged vessels that their sails pivot round their centres of effort and keep their balance in every trim. On the other hand, it is a quality of the fore-and-aft rig to lie closer to the wind, and probably to yield a given sail area with a smaller quantity of top hamper, thus suiting well the chief purpose of modern sails, to serve as auxiliaries to the power of steam.*

But iron masts, spars and wire rigging are daily coming more and more into use, and will eventually open up a new field for enterprise; at least in the merchant service.

* The majority of the French iron-clads carry large fore-and-aft sails, in lieu of square sails, probably on this account. And their sail area is, in general, quite equal to that of square-rigged ships of the same size.

CHAPTER XXI.

HOW TO DESIGN THE LINES OF A SHIP ACCORDING TO THE "WAVE" SYSTEM.

THE easiest problem which can be submitted to a constructor will be taken as an example.

Suppose a case which frequently occurs in practice, that a certain *length* of ship is to be built; a certain *breadth* is given, a certain *load draft* of water, and a certain *light draft* of water, and that these are about the ordinary proportions of a ship; that no particular *weight* is to be carried or *work* to be done beyond *sailing well* or steaming at a moderate speed; and that the purpose to be served is a fair, common mercantile trade, such as ordinary vessels will moderately well perform; of course the owner will expect, what he may with reason expect from a man of science and skill, that the vessel will be somewhat faster, easier, safer and more economical—therefore somewhat more valuable—than a vessel built, without design or calculation, by an unskilled man. This is a very ordinary task for a naval architect.

There are two ways in which he may set about building his vessel: he may either take the model of the vessel which is already the best that has been applied to the trade in question, and improve upon her, or he may at once throw all precedent overboard, and give his employer an entirely new design. The undertaking then will speedily shape itself as follows: Extreme length and extreme breadth being given, he may determine a *midship section*, such as will give him the requisite carrying power with good sea-going qualities. Next he will determine a *water-line* which will give the *highest speed* and *least resistance* of which that *length* admits; or he may decide to fit her for a given speed only, and adopt a water-line of greater capacity fit for that speed. Thirdly, he will adopt a convenient form of deck for the ship, and on these principal points will fill in what may be

called "a skeleton design," and frame an approximate calculation of the qualities of the ship, which may also be called "the skeleton calculation."

(1.) *To construct the midship section.*

In the choice of the *midship section* the naval architect is left free to exercise with the greatest liberty his own judgment. *In the water-line he has little choice,* since nature has fixed that for him. The midship section he may vary as much as he wishes to, and give the ship every sort of quality by choosing it ill or well; whence, with a given water-line, he may produce all sorts of ships.

To illustrate this latitude of choice, suppose the architect to take three styles of midship section; and further, that it is necessary for each of them to have the greatest speed the length will allow.

The first of these sections (fig. 16, page 74) is to carry very little cargo, to have little room, but to go as fast as she can be made to go with all the sail and steam power she can carry. These are the practical conditions of the yacht, the swift cruiser, the opium trader or the privateer; and what such a vessel requires can be readily contrived, for the conditions given *make* the midship section, and leave not much to choice.

Such a vessel must be all "shoulder" and keel (figs. 14 and 16), since, by being all "shoulder," with very little under-water body to carry, she will possess the maximum of power with the minimum of weight. Her fault will be that her enormous keel, necessary to prevent her from going to leeward, exposes a large surface to the adhesion and friction of the water. Nevertheless, it is the form of greatest power with the least weight. The bottom of this midship section may be formed in two ways; it may either be made *elliptical,* to have a minimum of skin for adhesion, and be reconciled to this deep keel, by two hollow curves; or it may be reconciled to the keel by a long wedge bottom. The *elliptical* bottom is thought best for *iron* ships; but the other or *peg-top* shape has been much used in *wooden* ones.* Next, suppose that the capacity thus got is too small for carrying remunerative cargo, and that a "cargo-hold" of a capacity more usual in mercantile vessels is required; in that case keep the same "shoulders," and give a larger under-water body. (Fig. 9, page 73.)

* Sir William Symonds' vessels, for example.

Now take a third design. The ship is to carry as much as is not inconsistent with good sea-going qualities; and she is to have room also for boilers and machinery of considerable power. This requires her sides to be nearly upright, her bottom *dead flat* amidships, with only so much off her bilges as will not be inconsistent with what she is to receive inside. (Fig. 7, page 73.) This the form and arrangement of her boilers and machinery will generally determine; and the boilers and machinery in such a vessel should be treated *as ballast and kept low.*

In regard to these three midship sections it is to be noticed that they are prescribed in some measure by the uses of the ship; but the forms mentioned come entirely from the judgment of the constructor, and whether they have been wisely or injudiciously selected must be judged of after the calculations have been made of the various qualities to which they give rise.

But there are one or two points which occur to a constructor at the first glance at these forms of under-water body. It is plain the first is easiest and the last hardest to drive. It would require much more sail or steam power to drive the two last than the first.

And it is equally plain that the first is much better able to carry sail than the last. The area of midship section of under-water body is the thing to be driven; the area of the sail is the driving power; but the power of the shoulders to carry the sail upright limits the quantity of sail the ship can carry. The bulk of the under-water body brings with it two evils—resistance to being driven through the water, and under-water buoyancy tending to upset the ship.

From these considerations it is evident that the first shape is suited for a fast ship under sail alone; the last is suited for a fast ship under steam alone; and the second form may do for a moderate quantity of both, or what is known as "the mixed system;" while of these three vessels the following will probably be an approximation to their qualities.

The first will be powerful, weatherly, lively and fast. The last will be tender, easy, sluggish and roomy. By a proper medium may be obtained, in the second vessel, any compromise of these qualities which may be fancied. (Fig. 8, 9 or 15.)

Nothing has yet been said about the parts of midship section above water; but these grow naturally out of the form adopted under water,

since the over-water body should be proportioned to the under-water body. The object of this is to give adequate lifting power in a sea-way in proportion to the heavier under-water body.

In the three designs the midship section (a technical term) is far from being actually amidships, being placed at the point of greatest breadth, or nearer the stern than the bow, in the proportion of 4 to 6. It is usually distinguished by the character ⊠.

(2.) *To construct the chief water-line.* (Fig. 25—*Half-breadth plan.*)

Draw a horizontal line, *oo′*, representing the whole length of the ship at the main water-line, and erect at the end of it two perpendiculars, OC′, O′C′. This line is generally called "the length between perpendiculars," or "the construction length," and these perpendiculars are to be the ruling elements in the construction.

Divide this length into ten equal parts; take four of these abaft for the length of the "*run*," and six of these forward for the length of the "*entrance.*" Describe a semi-circle on one-half, 8 8, of the chief breadth.* Divide the length of entrance, O8, and this semi-circle, 8 4 8, into any (and the same) number of equal parts;† the distance of the water-line from the centre line opposite each division in length of the entrance will be the distance of each corresponding division of the semi-circle from the same centre line, and a line through all the points thus found will be the true wave water-line, OA8, of the bow.‡ To obtain the water-line of the run, O′B8, it will be necessary to draw parallel lines to the centre line through each of the divisions of the semi-circle, which it may be convenient to call "the semi-circle of construction." On each of these lines points may be found, just as if it were a bow-line, the length of the run being divided into the same number of parts as the semi-circle. These lines must be prolonged aft, *beyond* the points thus found, to a distance equal to that part of the line intercepted between the semi-circle of construction, 8 4 8, and the main breadth, 8 8. The last found points in the parallel lines give the line of *main breadth.*

* The radius of this circle being ¼ of the extreme breadth.

† In this case *eight* parts are chosen.

‡ Or the perpendiculars to the centre line on the points of division of the entrance which intersect parallels to the centre line through the points of division on the semi-circle, will be the points for the "wave curve."

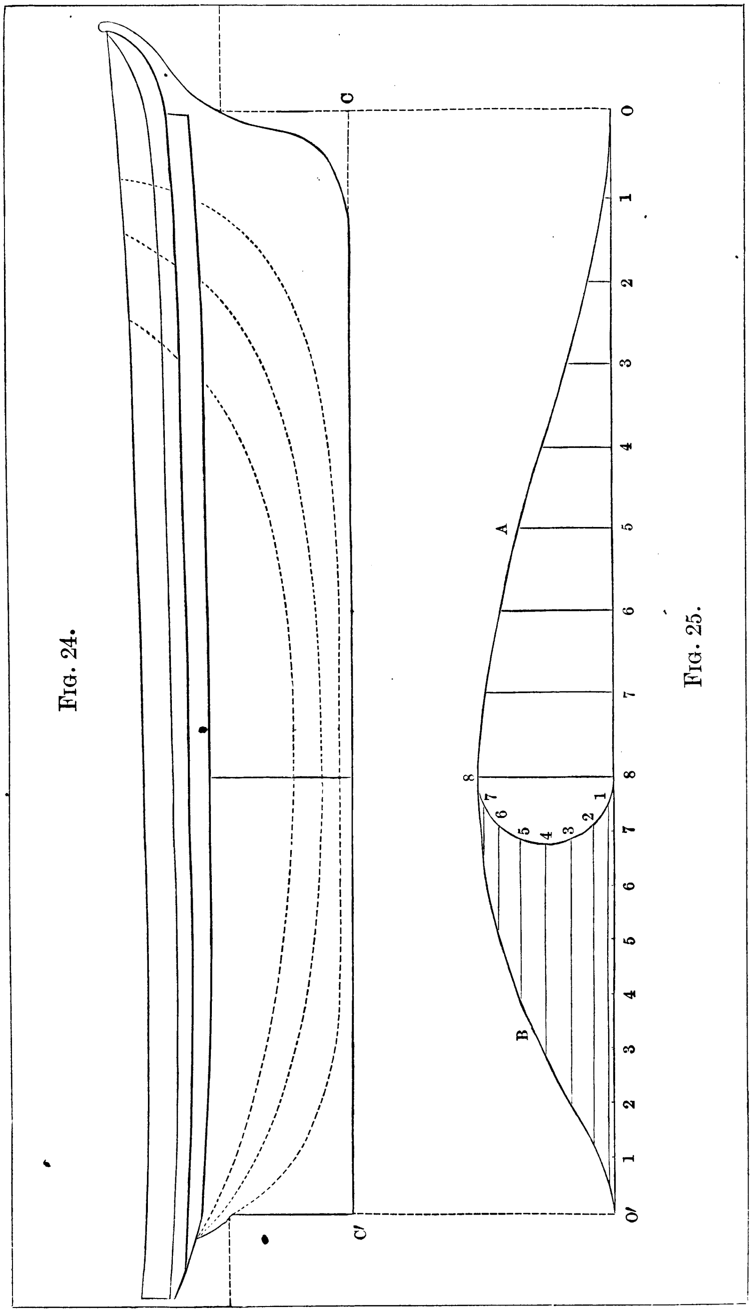

Fig. 24.

Fig. 25.

The chief water-line of the bow and of the stern, or the lines of entrance and of run for the greatest speed which the given length will admit, are thus formed. The lines thus given are *absolute*, and will admit of no deviation without some loss. Nevertheless, some modification in the application of these lines may be admitted as expedient, and one of them is obvious.

It will be seen that the point of the bow is so extremely sharp that it would be in continual danger of cutting everything that it touched, and being so fine would run risk of being crushed by rough usage. The stem also, for the rough work of a ship, must be of considerable thickness; and the practical question is: How can the line at the bow be altered to get this thickness? Shall the fine part be cut off and thus shorten the vessel? If so, she will be too short for the length determined on.

The answer to the question is: Draw the bow a few feet longer than it is intended the ship shall be; then cut off this water-line to the length it is intended to keep. The result obtained is a thickness of some inches between the two sides of the water-line, which is enough for the materials of the stem. By this means is obtained the extreme length required, and also the strength of stem necessary for durability; and it may also be observed that the bow thus gained is of slightly greater capacity than the first attenuated line. This is, therefore, called "the corrected water-line of the bow." No such adjustment is necessary at the stern. It is enough there to insert the stern-post simply by increasing the breadth between the lines to admit the thickness of the stern-post—a deviation insufficient to cause a sensible difference in the performance of the ship.

There is another modification of these water-lines of the fore and after bodies which may require further consideration. Both entrance and run have been put in the same plane, with the intention of leaving them so in the construction of the ship, but it may be necessary afterward for some good reason to change it.

The constructor must be prepared to do so. The main water-line may require to go lower or higher in the vessel than is now proposed, and the after part of it may have to go higher or lower than the fore part, in order to gain some advantage; but this change may be effected, if necessary, without in any way altering the character of the line already drawn; it is only necessary to

alter the height at which it should be placed, and not even that, unless required.

(3.) *The sheer plan.*

This gives the entire outline of the ship as we look at her sideways. The top line, or upper boundary, is the line of her deck or bulwark, or in short the top of the ship, which must be laid down in order to construct the *chief buttock-line* (see page 144); the bottom is the line of her *keel*, the front is the line of her *stem* or *cut-water*, and the after part is the line of her *stern-post.*

Begin with the stem, and make that line follow the form of the chief buttock-line and gradually grow out of it. This ought to be so, because buttock-lines bound equal thicknesses of the ship, and a stem is merely a thin slice of the ship, and therefore follows one of the buttock-lines. As a matter of beauty and of reason, therefore, it should be made a buttock-line in order that the outline may harmonize with the general form.

The form of the stem will depend on the decision taken with regard to the *deck-line* and the buttock-line, and if the deck-line be kept well aft, so that the main buttock-line tumbles home, the stem above the water will be curved backward, and so be in unison with the tumble-home bow, and it will be the contrary if the clipper bow be adopted. Above the water, however, the mere form of the stem itself is a matter, to some extent, of taste or fancy. If the general character of the bow give good buttock-lines, it will not matter much whether the stem to which they are joined curve out or in, except that it will always be better for the stem to harmonize with the character of the bow of which it forms the conspicuous outline. Some constructors, however, leave it perpendicular.

Below the water, on the contrary, the form of the bow is of the greatest practical value. It has been usual to carry the stem down to an angle with the keel, and continue the keel forward to meet the stem, thus forming what is called "*the fore-foot*" of the ship, giving it a great *gripe* or hold of the water. This gripe and fore-foot have every bad quality, being weak in structure and making the vessel hard to steer. It is thought better to cut it all off, following the shape of the other buttock-lines, and further to carry this *rounding* a great way back, say to *one-sixth* of the whole length of the ship.*

* See drawing of the yacht "America."

By this, not only does the constructor diminish the fore gripe and ease the steerage, but the stem and fore-foot is kept out of harm's way; and this has been known to save repairs and contribute to the safety of the ship. When turning in narrow channels, when steering in intricate or shallow waters, or performing evolutions under difficult circumstances, the fact that there is no thin, protruding part near the bottom to touch the ground and be broken off, or to impede or alter the movement or direction of the vessel, is often of great consequence.

By a gentle curve at the stem, therefore, the fore-keel and fore-foot are kept out of harm's way, and the same may generally be done at the stern, where dead wood can be spared. By curving the after part of the keel upward, like the stem, both keel and rudder are often saved and the ability to turn the ship certainly facilitated; of course it is done to a much less extent at the stern, as several feet of gripe at the bow will correspond with a few inches of trim by the stern.

But, though the keel and fore-foot are thus curved, the whole central part of the keel should be kept perfectly straight—if for no other purpose than to be able to support the middle of the ship on blocks in the dock. This is obviously necessary, since otherwise the keel would rest merely on points, instead of being uniformly supported; though in the dock it is rather an advantage that the two ends of the ship should not be borne by the blocks, unless they require special repairs, when they can be then propped up as may be needful.

It is not necessary that the keel should be parallel to the water-line, except where there is a narrow limit to the extreme draft of water; in which case, the keel should be parallel to the load water-line; in most other cases it should incline downward at the stern, so that the vessel will draw more water aft than forward.

In the case of screw steamers of great power, it is a necessity to have this draft in order to get the screw sufficiently large and sufficiently under water for effective power; while it is convenient in sailing vessels to be able to carry a large sail area on the after part of the ship, for which greater depth of keel aft than forward affords the necessary facility. It is convenient, frequently, for the same purposes, that a vessel when light should draw very much more water aft than forward, and that her lading should bring her down gradually to an even keel. This greater draft aft than forward is reckoned a main element in her trim.

Another element of the sheer plan is the *rake* of the stern-post, and great license is allowed here. The constructor may have the stern-post straight up and down, so as to make the rudder pivot fairly, or he may incline the *head* of the rudder back behind the perpendicular at an angle, or he may incline the *heel* of the rudder forward of the perpendicular; indeed, he may make the line of the rudder cross the perpendicular at any angle he may choose. In the *first* case, he will maintain the balance of his original draught; in the *second*, he will extend the deadwood and increase the lateral resistance to leewardliness; while in the *third*, he will decrease the lateral resistance, but increase handiness. In every intermediate degree between these two, he will gain one of these qualities at the sacrifice of the other.

The effect of this inclination on the rudder itself must not be forgotten. The inclination of a rudder increases its power to turn the ship, but it also increases the resistance which the application of rudder offers in every degree to the progress of the ship through the water. The action of the rudder, as has been already stated, is of the nature of a hindrance to one side of the ship, so as to allow the other side to go forward at greater speed, thus turning the ship; but the inclination of the rudder-post has a double effect, by which, when the rudder is held over, not only is one side of the ship hindered, but a certain quantity of the water which strikes the rudder is diverted upward as well as to one side. Nevertheless, a certain amount of rake should be given where very great power of rudder is needed.

Next comes the question of rake of *counter* and rake of stern. It is thought best to allow the buttock-lines to decide the rake of the counter, so that when the stern is deep in the water the counter may be a continuation of the true form of the ship and of her lines. A good counter of this sort will help the ship when the stern happens to be buried in the waves. As to rake of stern, it seems to be a matter of fancy, yet it is better that the stern should rake outward rather than it should tumble home.

The upper boundary line, which appears to finish the ship, is called "*the sheer-line*," and is also a mere matter of taste, though some points of it have more or less reason. In looking at a ship which has little sheer, she is apt to have the appearance, contrary to

the truth, of being rounded down—that is to say, as if drooped at the ends. Now this is universally agreed to be so ugly that a considerable sheer at the bow and somewhat less at the stern, are necessary to counteract it. Experience gives for a vessel of 200 feet length, a sheer or rise of about 2 feet at the bow and about 8 inches at the stern, but this is frequently exceeded.

So much for the quantity of sheer. The quality of it depends on the exact curve which may be adopted. A parabola is deemed best for the sheer curve, and to trace it proceed as follows: Dividing the vessel into ten equal parts—six forward and four abaft—rise forward successively 1, 4, 9, 16, 25 and 36 inches, and abaft ½, 2, 4½ and 8 inches. This gives a total spring of 3 feet forward and of 8 inches aft, and makes the bow 28 inches higher out of the water than the stern. This proportion will serve for vessels over 200 feet in length; but for smaller ones it would be an excess. Nevertheless, it is to be observed that even in very small vessels, especially when low on the water, a considerable sheer forward is useful to keep them dry.

The sheer line is important in its structure thus far, that it is usual to make the planking of the upper part of the ship, the line of the ports and the line of the decks follow the line of sheer, though it is sometimes convenient to deviate from this usual rule, and to make the decks follow any line that may be convenient for the internal arrangements.

For example, when a large and roomy forecastle is needed, without deforming the ship by raising the forecastle above the bulwarks, it can be obtained by running the line of the deck straight forward on the level, and so following the level of the water-line instead of the sheer of the rail. In this way the height of the top of the bulwark above the deck, which amidships might be 5 feet, might be 8 feet at the stem, and there is no practical inconvenience from this which is not more than compensated for by strength and usefulness.

(4.) *On the chief vertical longitudinal section or buttock-line.*

In the construction of this line there is much room for judgment; for though it does not possess such properties of its own as the water-line and midship section, it has the power of either increasing the good qualities or aggravating the evils which the ship will derive from those two primary lines. It is only secondary in importance to these, because by its means all the possible good springing from the

others may be favorably developed, marred or neutralized. It happens, also, that this has not heretofore received the attention it deserves; in many designs it is not even to be found. It is believed that its good qualities tend materially to the ease, dryness, comfort and safety of sea-going ships. Vessels for river service may afford to neglect it, but a practiced eye can detect in the faults of this line almost instantaneously the bad sea-going qualities of a defective design.

The chief buttock-line should be placed in a vertical plane parallel to the plane of the keel and the perpendiculars or central plane of the ship, and at *one-fourth* of her breadth from the plane on both sides.

In ordinary ships this line will be found to be of a most variable, vague and nondescript character. The "wave" theory adopts for it the vertical line of a sea wave, and it is thought that its conformity to that shape has everything to do with the ease of the vessel at sea. The vertical section of the common *sea wave* is the common *cycloid.* This must be elongated for a long, low vessel, and compressed for a short one. Three points through which it must pass have already been determined by the midship section and by the water-line, because, as this line is distant from the centre one-fourth part of the breadth, it must cross those three lines where they cross this vertical plane. These three points are the only ones which do not admit of a free choice; and it remains a part of the skill of the constructor to adopt such a cycloid as may consist with his general design and with the use of the ship. Each of the three midship sections given places the bottom of the buttock-line at a different depth under water, and each of the three requires a different cycloidal line to fit it. The nature of this cycloidal line has been long known to mathematicians as the only line in which a pendulum can so swing that its vibrations, whatever their extent, shall be equal-timed. There is a remarkable analogy between the swing of a pendulum and the roll of a ship, and there is an equally strong resemblance between the forces which exist in a wave and the forces which act on a pendulum; while the mathematics of a wave and of a cycloidal pendulum are nearly identical.

When, therefore, it was discovered that the forces which replace the water in the "*run*" of a ship are of the same nature as the forces

actuating a wind wave at sea in the vertical position, by this discovery came the key to the vertical lines of the after body of the ship; so the vertical lines of the fore body were contrived in the belief that wind waves coming into collision with a body already perfectly fitted to the form which they themselves take in undulating, unresisted free motion, would not be broken, but would have free way, and that they would glide as smoothly over the face of a solid cycloid as the layers of the same wave glide over one another.

Experience proved this to be so, and a vertical cycloid thus became the buttock-line of the bow of an easy and dry ship, just as it had already become the easy run of the wave of replacement in the stern of the ship.

The chief buttock-line is, therefore, described in the following manner: The after part is formed from a semi-circle, the bottom of which is at the intersection of the midship section with the vertical plane, and of which the uppermost point is as high out of the water as the constructor may choose to carry the bulwark. From this describe a cycloid, and cut off as much of the cycloid as may be desirable to adapt the portion of the stern beyond the perpendicular—a point which is a matter of room and comfort merely. There is choice as to whether the bow shall much overhang the water, or rise up pretty square, or tumble home.* For a vessel low in the water, the first might be adopted, but never for a vessel high out of the water.

(5.) *On the main-deck line.*

By the main-deck line is meant the outline of that deck which is intended to be kept in all circumstances well out of the water. It is this which constitutes the chief gun deck of a vessel of war; on which it is necessary, in all ordinary weather, that the ports should be open without the sea entering.

The choice of a deck line has a great deal to do with the usefulness of a ship for its purpose—more even than her behavior at sea. This main or construction deck is, in small vessels, the uppermost or spar deck; but in larger vessels there is a spar deck above it; in the old three-deckers there were three decks above it; and in the "Great

* The "tumble-home" bow is thought to be the dryest and easiest in a sea, but there is the vertical cycloid between the two. Each proportion and kind of vessel has its corresponding cycloid.

Eastern" there are four decks above it and four below. As a general rule, also, when a vessel is deeply laden, this deck is *an eighth* or *a tenth* of the beam of the ship above the water.

A little consideration of the purposes of a main deck will serve to indicate how various its shape may be. In a vessel meant to be fast, its point should be like the bow of the ship, fine and sharp, because, if a full, bluff deck is put on the top of a fine, fast bow, the ship is given the bad quality of pitching in a sea way; the fullness of the deck line will also take from the speed, counteracting the very quality intended to be gained by the sharp bow under water.

The argument in favor of sharpness seems inconsistent with a roomy deck forward, which is usually obtained by a broad bell bow, flaring out wide over the water. Such a bow the old school still believe in, and modern constructors would never have succeeded in introducing the fine sharp deck in opposition to traditional prejudice, had it not been that the full deck line was found fatal to speed.

There can be no doubt that in fine weather a large, roomy deck forward is convenient for doing the work of the ship comfortably and handily. It is far more convenient in the man-of-war than in the merchant ship, since in chasing it is desirable to work chase guns through the bow ports clear of everything, and to work them well in that position. It has been pretended that it was impossible to do this on a sharp, fine deck line, but this has proved a crotchet of the past.

The simple fact is, that the roominess, dryness and comfort of a full deck line, instead of a fine one, is mere impression or belief—nothing more. If it is imagined that a fine bow is got by cutting off so much room from a full bow, and so diminishing the extent of available deck room for working ship, then the fine bow may be considered narrow and confined, but the practical fact is the contrary of this. The fine deck line of a modern fast ship is *not* got by cutting anything off the length, or off the width, or off the roominess of a deck; the sharp bow is obtained by adding on a fine entrance to a bluff one, and by lengthening the deck; the full parts of the ship and of the deck remain where they were. All that is necessary, therefore, is to see that the working parts of the ship shall, in the fine bow, be kept well aft in the broad, open space of the deck, and not crammed forward into the narrow space superadded, which

should be kept perfectly clear. It is a further peculiarity of the fine bow and deck line, that the foremast stands much farther aft than in the old full bow, and that there is more room forward of the mast; but care must be taken to keep windlass or capstan, catheads and anchors, and all working parts of the bow, well aft—not for room merely, but also to keep heavy weights out of the extreme bow of the ship, where they are always detrimental.

It is sometimes a good plan to cover in the whole of the fine part of a deck forward, with a light forecastle, bulkheaded off, especially in iron ships. It is a great convenience, and affords good quarters for the crew; it keeps the head light and dry, while abaft the forecastle, a broad, roomy deck is still to be found. There is, however, another way of giving a roomy deck on a sharp-bowed vessel, and it has been tried with success in men-of-war. An extremely fine bow has been made to carry two long guns, parallel to the keel, through two wide ports, with ample room all around to train and work them freely. This was accomplished by shortening the deck, or stopping it very much short of the bow, carrying the bulwark round the bow considerably behind the stem; the real deck beyond the bulwark forming part of the *head*, which, instead of being grated and overhanging the sea, had a solid oak deck over the greater part of it, leaving the head as convenient as before. In this way the bulwark of the deck left the real line of the ship 30 feet short of the stem.

There is yet another way of placing a full, round, capacious deck line on a fine, hollow, fast water-line, and yet perfectly reconciling them one to another, so as to form a handsome, symmetrical sea-going vessel. This is to carry out the tumble-home bow, which makes a vessel dry, easy and safe. To carry out this system, it is only necessary to take a tolerably full, easy deck line, composed of two circular or two parabolic arcs, laying them over the water-line, and so far behind it as to be easily reconciled with it by means of the cycloidal buttock-line; a process which will be guided in a great measure by the point at which the cycloidal buttock-line already drawn meets the level of the deck.

Large, capacious, roomy sterns are part of the wave form, and though apparently unsightly, give great room with less cost and sacrifice than any other part of the vessel. A small, handsome, light stern may be pretty as an eye model, but it is a costly whim. There

are no good qualities in a ship which are not improved, and no economy which is not enhanced, by a large roomy stern and deck line. In a merchantman, it gives large passenger cabins, airy as well as roomy, and is that part of a ship which pays the owner best. In the ship of war, it gives a fine, roomy poop, and plenty of space for working a heavy pivot gun. But the roominess and fullness of the stern in the neighborhood of the deck line is the greatest element of safety in that most perilous of positions, scudding in a heavy gale and sea; and in most cases may be used with advantage to embrace the stability and sea-going qualities of the vessel.

The best way to turn the stern to advantage for room and wholesomeness is to carry the breadth on deck well aft, to taper the ship in toward the stern but little, and even, if necessary, to carry the projection of the stern a good way abaft and beyond the perpendicular, following, however, and not extending beyond the vertical buttock-line already given. But then a question arises, Shall the stern be *round* or *square?* The answer is that its bulk is the main point; its shape is of less consequence. If, as a matter of taste, the corners are cut off, it becomes a *round stern;* and nothing is more common than to see constructors cut off the stern inside and then stick *quarter galleries* on the outside to make up for the corners cut off. When little is cut off, it is usually called "*an elliptical stern,*" although it never is an ellipse; and when much is cut off, it is called "*round,*" though it never is circular. So far as the qualities of the ship are concerned, the precise outline of the deck astern is of little importance.

The constructor is now prepared to adopt a definite form for his deck line, which is plainly a compound affair of policy and taste. For a trial line it is thought best to use forward two arcs of a circle, intersecting at the bow, and having their centres on a line drawn athwartship, halfway between the perpendiculars; thence inclining by two parabolic arcs, gradually narrowing to the breadth of the intended stern; and for that breadth the constructor should adopt, at the point where it passes the perpendicular, some specific proportion —6, 7 or 8 tenths of the midship breadth; finishing with whatever straight line or curve may have been determined on as regards room at the stern. Indeed, in a vessel of no great length, and without much overhanging counter, no harm is likely to arise from carrying

the full breadth of the deck amidships right aft to the stern, with merely sufficient curvature to give an agreeable line.

The completion of the design now requires that these four ruling lines be reconciled with one another. In this operation what the constructor must keep mainly in view is to extend as far as possible, through all the remaining lines of the ship, the good qualities which have been established in the ruling lines.

(6.) *On the lower water-lines.*

It is most desirable that the water-lines of the entrance should be as exactly as possible of the same form, on reduced breadth, as the main water-line. There will be some difficulty in doing this, especially near the keel; and the tendency of these lines will be to elongate themselves forward. This is to be avoided. The remaining water-lines of the after body are to be constructed on nearly an opposite principle. They are to deviate rapidly from the chief water-line of the after body already drawn, and this they will do naturally, because the main buttock-line which rules the after body compels the water-lines to increase rapidly in fineness as they go down in the water, and to extend rapidly in fullness as they rise to the surface; thus giving what is believed to be the best kind of stern—namely, very fine below and very full above.

In this respect it is a contrast to the bow, which is kept as full as may be consistently with the chief water-line all the way down. It is desirable to have at least three complete water-lines, in order to form a first approximation to the complete calculation of the ship.

(7.) *On the completion of the vertical cross sections or body plan.*

The cross sections are all to be regarded as midship sections modified, but each of them giving to the part of the ship where it lies qualities which either enhance the good qualities of the midship section or impair them.

A vessel with a fine, powerful midship section may easily be impaired by weak extremities, and a weak midship section may be reinforced by good cross sections, especially in the after body.

What the designer has to bear in mind, then, is to study how far he can enhance, support and carry out the qualities of the midship section in the rest of the body. In this he will be materially aided by the choice which he makes of that cross section which passes through the after perpendicular. To this frame, being absolutely

out of the water, he may give any shape he pleases; and having fixed this, he will find that with the main buttock-line it rules the entire form of the after body, and also controls materially the surface of the water-line of the stern. It is this stern cross section which should be made very full, in order to turn the after body to the best possible account. But this fullness must not be abrupt; otherwise, when rising and falling in the sea, the counter may at times strike the water with violence.

The circumstance that this portion of the vessel remains so entirely subject to the will of the designer makes it, for the inexperienced, the most difficult to decide and determine upon; and a greater variety of forms will be found in the region of the stern above water than in any other part of a ship.

The vertical sections of the after body, followed out in the manner indicated, will be found as they approach the stern to have become very fine below and very full above, and so they should be; but in the bow there will generally be found a similar tendency of the lines to become extremely fine below and to grow full above, and there it is necessary to counteract this tendency instead of encouraging it, as abaft. The bow cross sections must, therefore, be made to maintain their full breadth well down toward the keel, and they must not spread out too rapidly at the surface of the water and above it.

The reason why the fullness should be preserved below is, that it is the business of the fine part of the bow, or cut-water, to displace or remove the water out of the way of that part of the ship which is to follow; and if the bow part be cut away too fine, this work will not be done, and the part behind will still have the work of displacement, with a bluffer entrance and a shorter time to do it in; which is the same as to say that it would then require unnecessary force by causing unnecessary resistance. The main water-line having, therefore, already rendered the bow sufficiently fine for the service of dividing the water, care must be taken not to carry this fineness farther than necessary, or than it is carried in the chief water-line.

Much care will be needed to prevent the cross sections of the bow from flaring out very much to meet the line of the upper deck. To avoid this, keep that line fine, and throw it as far backward from the fore perpendicular as conveniently practicable. The cycloidal buttock-line, properly used, will help to throw the deck back and to pre-

vent it from spreading over the fine bow; nevertheless, it will always be difficult to reconcile the wave water-line, the full deck and the cycloidal buttock-line; but when it is well done, it makes the most beautiful as well as the best of all sea bows. In vessels for river service it does not matter how much the deck flares out, or how much it overhangs the water; it is in the open sea that the true skill of the naval architect is to be developed.

It is not the best voyage in *fine weather*, but the best behavior in *bad weather*, which gives reputation to the truly *seaworthy ship*.

CHAPTER XXII.

THE "WAVE" SYSTEM OF CONSTRUCTION COMPARED WITH OTHER SYSTEMS, AND ITS ADVANTAGES.

THERE is hardly a vessel at the present day (at least abroad) which possesses *high speed* with a *moderate* consumption of fuel which does not possess a certain number of the characteristics of the "wave" principle. Nearly all eminent and scientific as well as *practical* constructors and builders have adopted the main features of the wave system and carried them out successfully in practice.

It is quite possible, however, to understand the wave principle and yet design a bad ship. Knowledge of the *principle* does not supersede the knowledge of other principles of naval construction; it merely adds to their number. All it does is to enable a scientific architect to combine with certainty the properties of high speed, small resistance, economical transport and sea-going qualities under circumstances where formerly it was guesswork merely.

The following are the main points of practical construction determined by the wave system:

1st. *The entrance of a ship designed on this principle may have a* HOLLOW *water-line.* The advantage of a hollow line is, that if the material of the ship is wood, the structure is much more easy (hollow lines having a strong tendency to creep into any ship's design) and *stronger* than a convex bow water-line. In any structure the hollow line has the virtue of diminishing the room for carrying weights in those parts of a ship where it is injurious to sea-going qualities to carry them.*

2d. *The "run" of a ship may have a convex water-line.* The fine run of the old-fashioned, bluff-bowed ships was given on account of

* To carry weights (as in wave ships) near the middle and relieve the ends is to give a ship some of the best qualities she can possess.

steering qualities, since a full-bowed ship *must* have a fine run in order to steer well. The fault of this fine run, however, was that it sacrificed much stowage in that part of a vessel where it is valuable, whilst after all, in many cases, it failed to correct bad steering.

The wave principle provides also for a fine run, but it does so in the right way and in the right place, as it makes that fineness lie well below the surface or deep down. It shows that fineness below should be well aft, and not where capacity is wanted.

3d. *The entrance of a ship designed on the wave principle may be as long as the run and even longer.* This is also a release from the trammels of the old system, in which every constructor had his own proportions—some 2 to 1, others 3 to 2, others 4 to 3, others 5 to 4, and so on. The knowledge that the "entrance" may be made even longer than the "run" is valuable where the length is limited, so that it is difficult to obtain by any means a fine hollow bow. In circumstances of very limited length this knowledge may be very useful, especially in building the small class of sailing merchant vessels, yachts and steamers, where good speed is needed under restricted dimensions.

4th. *The main breadth may be placed nearer the stern than the bow.* This follows as a necessary consequence of the wave system, as the chief water-line of the entrance being made longer than the run naturally throws the midship section farther back. It is occasionally expedient to place the greatest breadth well abaft the middle in the upper water-lines of a vessel, and well forward of the middle in the lower water-lines of the same ship. This expedient may be found useful in forming designs for speed upon dimensions that are much restricted. Such a distribution of breadth before and abaft the middle may be given by the wave system, but by no other.

When it is required to construct the bow water-lines of a ship, of which the breadth and length of bow are given, so as to give the vessel the form of least resistance to passage through the water, and obtain the highest velocity with a given power, halve the greatest breadth of the vessel at the midship section; and at the centre of this breadth, and at right angles to it, draw the centre line of length of the bow. On each half breadth describe a semi-circle, dividing it into, say, eight equal parts (fig. 25). Divide the length also into an equal number of equal parts. The divisions of the semi-

circle, reckoned successively from the central line, indicate the breadths of the water-line at the successive corresponding points of the line of length; and the line traced through all the points is the water-line of least resistance for a given length of bow and breadth of body—in short, the wave water-line.

The half-breadths of the water-line are the versed sines of arcs of the semi-circle described on the half-breadth, corresponding in order to the places where these half-breadths lie on the length. The *wave water-line* is, therefore, geometrically considered, *a curve of versed sines*, or simply *a curve of sines*; and this water-line is of a similar form to a *wave of the first order*, propagated through water of a considerable *depth*.*

The full bow, the straight bow and the hollow bow have had for some years their respective advocates among professional ship-builders, as the various forms give various qualities—the practical problem being to select those forms most fit for special use.

In regard to the wave line, it is conceded that it is inferior to the convex in capacity, or displacement, on the same midship section and length of entrance. The convex water-line has (when of the parabolic form) a larger area than the wave-line, in the proportion of 6.66 to 5.00.

For a slow vessel the parabolic entrance has the advantage in point of capacity. But that will be a mercantile point of comparison between the value of speed and capacity in a given case.

The straight-line entrance has no greater capacity than the wave-line entrance. The advantage of the wave-line entrance over the straight entrance is, that it carries its capacity and weights in a better place and nearer the middle of the ship, which is of great importance, for to remove weights from the ends to the middle is what every constructor aims at and every wise commander endeavors to carry out.

This makes the wave vessel the safest and best sea boat.

In the parabolic line the centre of weight is 0.37 from the middle. In the straight line, the centre of weight is 0.33 from the middle. In the wave line, the centre of weight is 0.29 from the middle.

In point of stability, the wave bow is superior to the straight bow, and in a sea way the motion of pitching and 'scending is less in the wave form than in either of the others.

* Hence the terms "wave-line ship," "wave theory," etc.

The advantages and disadvantages of the three bows are therefore nearly as follows:

TABLE XV.

Convex Parabolic.	Straight Line.	Wave Line.
Greatest capacity, 0.66.	Less capacity, 0.5.	Less capacity, 0.5.
Greatest resistance.	Less resistance.	Least resistance.
Greatest stability.	Least stability.	Less stability.
Greatest pitching.	Less pitching.	Least pitching.
Worst place for weights.	Mean place for weights.	Best place for weights.
Worst for strength.	Mean for strength.	Best for strength.
Worst for injury at sea.	Mean for injury at sea.	Safest at sea.
Least speed.	Mean speed.	Greatest speed.
Much waste of power.	Much waste of power.	Least waste of power.

The wave line of the after body is less definite than that of the fore body, and admits of variations which allow greater freedom of choice.

The water in filling the *wake* abaft the midship section of a ship takes the form of a *wave of the second order*. That it may fit it, the run of a ship ought to fit the line of that wave.

To apply this in practice to the after body of a ship of a given length and breadth of which the water-line of the entrance has been already formed, the run may be divided into say eight equal parts (fig. 25), which call 1, 2, 3, 4, 5, 6, 7, 8. Describe a semi-circle on half the main breadth, and divide it into the same number of equal parts as the run, and in the same order draw lines from each point in the semi-circle parallel to the middle line, and equal to the parts 1, 2, 3, 4, 5, 6, 7, 8 on the length. The ends of these parallels are points in the water-line required.

The curve of the after body is, therefore, of the kind commonly called *cycloidal* or *trochoidal*, and, though not identical with the curve of the bow, belongs to the same family of curves.

This curve is the same as that of the *front of a common sea wave* approaching a shore, and it is the curve which water, filling up an opening artificially made in it, naturally assumes in the process of filling up.

It should be noticed that while the water-line of the bow has an

invariable *concavity*, that of the after body may be even quite *convex* in extreme cases. This depends on the relative length and breadth in the after body, while in the fore body it is constant. The whole of the wave water-lines of the fore body may be so constructed as to follow all the characteristics of the chief water-line; but in the after body those water-lines which are lower down than the principal water-line may, and in many cases must and should, vary entirely from that of the principal water-line, which is to be taken at or near the surface of the water. The reason for this is that the particles of water at the bow, acted on by a wave fore body, do, in general, take motions which closely resemble each other from the bottom to the top of the water. On the contrary, the particles entering the run take motions in entirely different planes. Their motions vary as follows: Those on the surface move nearly in a horizontal plane; those near the bottom nearly in a vertical plane, and the depth of a ship materially effects the direction of motion of the particles.

In a shallow vessel much of the motion of the particles is in a vertical plane and little in a horizontal one; in a deep ship it is just the reverse. The shape of the midship section also powerfully affects the direction of the particles starting on their run into the wake.

To determine the best form of after body, it is, therefore, expedient to construct a *vertical* wave-line on the run as well as a horizontal one, and in designing light-draft vessels to give more weight to the *vertical* wave-line than to the horizontal one. There is therefore in *the after body a wave buttock-line* as well as a wave water-line; and this is useful, for the run of a ship is more complex than the bow, in consequence of the place of the rudder being aft; the best action of the rudder being a point to which minor considerations must give way. The two lines therefore enable the designer to give more or less fineness as he finds it necessary to affect the steering power.

Screw vessels also require a judicious choice to be made between vertical and horizontal fineness. Fineness below is considered much more valuable, for the good action of both rudder and screw, than fineness above.

The practical advantages to be given to a ship by means of the wave-line after body are as follows:

Great capacity of after body;

A very fine run below water;

Great area of water-line near the surface, where it is of course most valuable;

Great stability of a good sort, and given in a good place for sea-going qualities; and lastly,

Least resistance and greatest economy of power.

There is, therefore, no principle given by the wave method of construction more important than the following: *That there is a fixed proportion between the speed for which a ship is to be designed and the length of entrance and run* which must be given to her in order to fit her for that speed.

The importance of obtaining such definite proportions has long been felt by practical men, it having been found very difficult, by any amount of power, to push vessels of certain length and shape through the water at high velocity. Power and money have been wasted in vain attempts to make ships of unsuitable dimensions attain high speed. Vessels have been filled with boilers and machinery designed to compel the performance of high velocity. Instances are known where a double amount of steam boiler was provided to compel high speed in an unsuitable vessel, and afterward these boilers had to be removed, the higher speed being found impossible in that kind of ship, and the highest speed of which the ship was capable was afterward brought out with half the power. The wave principle has produced the proportions in Table XVI.; the cause which fixes these proportions being that the length of the fore body of a ship designed on the wave principle must be the same as the length of a *wave of the first order*, which moves with that speed; while the length of the after body must be the same as the length of the *front face of a wave of the second order*, moving with that velocity.

The wave system, therefore, destroys the old idea of any proportion of breadth to length being required for *speed*. An absolute length is required for the entrance and run; but these being formed in accordance with the wave principle for any given speed, the breadth may have any proportion to that which the uses of the ship and the intentions of the constructor require. A vessel meant to go ten knots can be efficiently propelled at that speed, if her length and form be right, whether she be 3 feet beam or 30 feet.*

* Of course it will be understood that the *steam power* required to drive her that speed will depend on the area of ⊠ section and surface of skin immersed.

In designing wave vessels it is necessary, however, to distinguish carefully *three* elements of construction, viz.: The *fore body*, the *after body* and the *middle body*. The lengths of the fore body and after body are indicated by the required speed, and if the beam is fixed, it is only by means of a due length of middle body that the required capacity, stability and such other qualities are to be given as will make the ship as a whole suit its use. Therefore middle body is an element demanding the careful study of the designer.

It only remains to notice the errors sometimes committed by the novice when designing vessels on the wave system. Finding that a hollow water-line is admissible, he rushes to the extreme and makes it *too hollow*, and gets increased resistance; or that a fine, long entrance is good, he makes it *too long*, and gets increased surface; or that a full after body is admissible, he makes it *too full*, and spoils the steering qualities of the vessel.

On the other hand, instead of going too far, he may stop short too soon. When the water-line near the bow is made fine and the deck allowed to remain full, the end of the ship is overloaded, and so the value of carrying weights in the centre is sacrificed to a custom. It is most unwise not to reduce the weight and bulk carried out of the water. No error is more common than to give wave-line vessels greater fineness than is required for the special case, to the sacrifice of the carrying qualities of the ship. The best way of avoiding these errors is for the constructor not to adopt the system too hurriedly, nor introduce it too largely into his first design. Let him take the lines of a ship already built, and only alter them in a small degree on the wave principle. He will thus find out how far he has made an improvement, and how far he has altered the ship's practical points. Next time he may make a further change in the same direction, thus avoiding the error of rushing to an extreme, than which there is nothing more fatal to the success of a new method. A ship all ends with no middle, all top with no bottom, all dead wood with no capacity, is precisely one of those caricatures of the wave principle of which the world has seen a great many, misnamed "clippers," in which the true purposes and uses of a ship have been lost sight of in the attempt to gain great speed *at the expense of every quality which makes speed desirable.*

To guard against such errors, let it never be forgotten that the end

of all ship-building is to work out the purposes of the owner. A ship of war has to fight, and a merchantman to carry cargo. To build a man-of-war which cannot fight her battery is a much greater fault than to make her slow. To build a merchant vessel so as to have great speed at great cost, without the capacity necessary to repay the owner his outlay, is folly, since freight is the owner's object, and to earn the greatest freight is the problem submitted to the constructor. When the speed wanted for the trade is known, the wave principle gives the length of entrance and run to obtain that speed. When the cargo to be carried is known, the constructor can say what buoyancy he needs, and what length of middle body will carry the bulk and weight. When the draft of water is given, he is ready to decide what form of midship section will give the stiffness and weatherliness needed. When he knows the weights to be carried and the bulk to be stowed, he must take care that he carries them where they are supported by the water, and not where, being unsupported, they weaken the ship and increase its strains. If he thus keeps the uses of his ship steadily in view, he will find the principles of the wave system a safe guide to enable him to give his design those qualities, without a sacrifice of other qualities which can alone enable ship-owners or governments to avail themselves of his science and skill.

TABLE XVI.

Proportions of Bow and Stern for Wave-line Ships Designed for a Given Speed.

Length of Entrance and Run.			Length of Entrance and Run.		
Statute miles per hour.	Length of Entrance. Feet.	Length of Run. Feet.	Statute miles per hour.	Length of Entrance. Feet.	Length of Run. Feet.
1	.42	.3	11	50.82	36.3
2	1.68	1.2	12	60.48	43.2
3	3.78	2.7	13	70.98	50.7
4	6.72	4.8	14	82.32	58.8
5	10.50	7.5	15	94.50	67.5
6	15.12	10.8	16	107.52	76.8
7	20.58	14.7	17	121.38	86.7
8	26.88	19.2	18	136.08	97.2
9	34.02	20.5	19	151.62	108.3
10	42.00	30.0	20	168.00	120.0

The lengths increase as the squares of the velocities.

TABLE XVII.

Direct Head Resistance at Different Speeds on each Square Foot of Midship Section.

(Power required to propel a flat-fronted vessel through the water.)

Speed.		Propelling force in lbs. to the square foot.	Propelling horse-power.
Knots an hour.	Feet a second.		
1	1.68889	2.85235	0.00876
2	3.37778	11.40938	0.07007
3	5.06667	25.67111	0.23649
4	6.75556	45.63754	0.56056
5	8.44444	71.30865	1.09484
6	10.13333	102.68445	1.89188
7	11.82222	139.76495	3.00424
8	13.51111	182.55014	4.48446
9	15.20000	231.04003	6.38511
10	16.88889	285.23460	8.75872
11	18.57778	345.13387	11.65786
12	20.26667	410.73780	15.13506
13	21.95556	482.04647	19.24290
14	23.64444	559.05980	24.03392
15	25.33333	641.71785	29.56068
16	27.02222	730.20056	36.34868
17	28.71111	824.32799	43.03160
18	30.40000	924.16012	51.08086
19	32.08889	1029.69691	60.07607
20	33.77778	1140.93840	70.06976

Resistance varies as the square of the velocity.

TABLE XVIII.

Showing the Comparative Areas of Water-way, Resistance and Carrying Power to be obtained by Different Dimensions under the same Shape.

Elements of First Cost.			Working Cost.	Remunerative Work.
Breadth.	Draft.	Length.	Resistance or Water-way.	Floating weight or tonnage.
12	6	72	60	100
18	9	108	135	337
24	12	144	240	800
30	15	180	375	1,500
36	18	216	540	5,400
42	21	252	735	8,575
48	24	288	960	12,800
54	27	324	1215	18,125
60	27	360	1350	22,500
66	27	396	1405	27,125
72	27	432	1620	32,400

TABLE XIX.*

Showing the Measures of Value of the Hollow Bow or Approximate Wave-line Entrance in Diminished Head Resistance.

Speed in knots.	Length in feet.	Beam in feet.	Entrance in feet.	Values in diminished head resistance.
10	100	20	60	$(\frac{20}{60})^2 = \frac{1}{9}$
12	144	24	86	$(\frac{24}{86})^2 = \frac{1}{13}$
14	196	28	117	$(\frac{28}{117})^2 = \frac{1}{18}$
16	256	32	153	$(\frac{32}{153})^2 = \frac{1}{23}$
18	324	36	194	$(\frac{36}{194})^2 = \frac{1}{29}$
20	400	40	240	$(\frac{40}{240})^2 = \frac{1}{36}$

TABLE XX.

Force and Steam-Power Required to Drive One Foot of Area of Water-way and One Foot of Skin.

Speed.			Force exerted by one horse-power.	Force required to propel one foot of midship section. Wave form = 0.05.	Force required to propel each foot of smooth wet skin.
Feet per second.	Miles per hour.	Knots per hour.			
		5	65.19	3.565	0.250
	6	......	62.50	3.872	0.272
9	......	......	61.11	4.050	0.284
		6	54.32	5.134	0.360
	7	......	53.57	5.270	0:370
		7	46.56	6.988	0.490
	9	......	41.67	8.712	0.612
		8	40.74	9.127	0.640
	10	......	37.50	10.756	0.755
		9	36.21	11.552	0.810
	11	......	34.10	13.014	0.914
		10	32.59	14.262	1.000
	12	......	31.25	15.488	1.09
		11	29.63	17.257	1.21
	13	......	28.85	18.177	1.37
		12	27.16	20.537	1.44
	14	......	26.79	21.081	1.48
		13	25.07	24.102	1.69
	15	......	25.00	24.200	1.70
	16	......	23.44	27.534	1.93
		14	23.28	27.953	1.96
	17	......	22.06	31.084	2.18
		15	21.73	32.086	2.25
		16	20.37	36.450	2.56
		17	19.17	41.216	2.89

* The breadth of beam in feet divided by the length of the entrance for a given speed gives a decimal or vulgar fraction, which, being squared, represents the value in diminished head resistance.

CHAPTER XXIII.

ON THE FIRST APPROXIMATE CALCULATION OF A DESIGN.

I. *Area of midship section immersed.*

THE area of the midship section furnishes the chief measure of resistance of the ship, and the propelling power must be duly proportioned to it, each foot of cross section requiring a given number of pounds of force to drive it through the water at a given speed. Thus, if one foot of midship section should require 30 lbs. of force to drive it through the water at the rate of 10 miles the hour, this 30 lbs. must be supplied either by horse power, engine power or sail power. It is plain, therefore, that for each unit of section must be found a corresponding unit of propelling power.

II. *Surface of skin immersed.*

The skin of a ship might be thought to be so perfectly smooth and water so limpid as to slip from it; but such smoothness is imaginary, and water adheres. For a short race, boats are lubricated with grease or polished with black lead, and ingenious mechanics have invented a plan for iron ships, of blowing a film of air between the skin and the water to cut off the adhesion of the water. The reason why copper has been introduced is, that from a peculiar quality of that metal, sensible to the touch, friction is lessened and smoothness gained.*

With or without lubrication, it is a fact that water sticks to the skin of a ship, and that the skin drags the water with it; hence smoothness and lubrication mitigate, but do not annihilate it. For wood and copper, this drag is reckoned at a loss of nearly 1 lb. of

* This may be practically exemplified by rubbing one's finger over a smooth, bright sheet of copper that has been dipped in salt water; it will be found to have the same slippery feeling as the side of a freshly-caught fish.

force at 10 knots per hour, while on the surface of a common iron ship it may be as much as 2 lbs.; and this loss increases with the velocity, and in high velocities is an important element not to be omitted. The surface of skin is, therefore, an element in the calculation of a ship, and, adding to the work to be done, should receive separate consideration.

III. *Area of light and load water-line.*

The area of the water-line is a material element in the power of a ship to carry sail, to carry top weight, to acquire stiffness, to ride easy and *to roll gently.* It is very common to measure it by the proportion it bears to the midship section, and it is practically found to be from *six* to *twelve* times that area, though sometimes more.

There is another manner in which its value may be generally expressed—namely, its proportion to a rectangle, in which form it shows how much of its area has been sacrificed to shape.

IV. *Area of the longitudinal section in the water.*

This area is to *weatherliness* what the area of the midship section is to *resistance,* only the object to be obtained is the exact opposite. The midship section should be in area *small,* to obviate resistance; the area of the longitudinal section should be *large,* in order to create resistance. Area of longitudinal section, when small, indicates leewardliness; when large, weatherliness. It is quite plain that area of load water-line and area of longitudinal section have an important and close connection, since, if a large area of load water-line be combined with a small area of longitudinal immersed section, the vessel will have power to carry much sail, but this power will be wasted by leewardliness; while, on the contrary, a small area of load water-line may reduce her stability, so as to prevent her from carrying as much sail as her large weatherly area would enable her to bear without unduly drifting to leeward. These three areas are therefore evidently bound up together in the constitution of a ship, as a given area of midship section will plainly want a large power to drive it, and that large power will want a large area of load water-line to carry it; while great power to carry sail, or stability, will want large longitudinal area to utilize it.

The problem is, therefore, to obtain out of the three the greatest aggregate of useful results in these points without the sacrifice of higher value in other good points.

V. *Volume of under-water body or displacement.*

The four former elements are *areas* merely; and they measure the resistance to be overcome in doing the work, and the power to be used in overcoming this resistance; but the element of *displacement* represents the purpose for which they all combine—namely, the movement of a large mass of matter from place to place by means of the floating power of water. The constructor must find out what is the real mass to be moved, or what is the total volume of water which is to be displaced, in order that this body or ship may float in the place of this water. To do this he must obtain a precise measure of the volume of the body to be immersed, and the weight of that bulk of water will exactly measure the whole weight of the ship and contents. He must, therefore, calculate the number of cubic feet which the body of the ship contains—*first*, up to the light water-line when she floats without load; and *secondly*, when she is full ladened with cargo, stores, persons and provisions for the voyage.

The calculation of displacement is a problem of geometry; the constructor measures the bulk of the part of the ship under the light water-line, and allows one ton of weight for each 35 cubic feet (fresh water, 36); this gives the number of tons which the ship with all her parts and appendages must weigh in order to float at the water-line required.

Between the light water-line and the load water-line lies another part of the ship, all of which will be immersed when she is laden to the load water-line. The bulk of this part must be measured exactly; and this bulk, at the allowance of 35 cubic feet per ton (fresh water, 36), will show what the additional weights are which the ship will carry at the intended load water-line. The displacement of this part of the ship measures the load she will carry.

The calculation of the displacement is, therefore, mere mensuration, or a sort of superior kind of *gauging.*

Besides the absolute quantity of the ship expressed in tons or cubic feet, it is convenient to express the bulk in terms of her extreme dimensions. If the ship were a mere box, her bulk and displacement would at once be found by multiplying together her length, breadth and depth; the product of these in feet divided by 35 (or 36) would be the displacement in tons of that part of the box (or ship) immersed, and would therefore represent the weight of the whole.

But the ship may be supposed to be a box with its corners pared off, and it will, therefore, sufficiently express the deviation of a ship from the box form if the constructor places it so as to show how much of the box is lacking. He therefore expresses the volume of his ship by the fractions $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$ or $\frac{8}{10}$, or decimally, 0.5, 0.66, 0.75 or 0.8, to show how much the bulk retained in the ship is less than it might have been if the corners had been kept on. It truly represents the sacrifice of quantity to quality in a ship of which the extreme dimensions have been determined, and the fraction is called "*the co-efficient of fineness.*"

VI. *Volume of shoulder or stability of the ship.*

The "shoulder" has been defined to be that part of a ship which is alternately *immersed* or *emersed* as she is equally inclined from one side to the other. This inclination is here assumed as 14° on one side and 14° on the other, which gives about one-eighth the beam of the ship as the heel of the "wedge."* Men-of-war in smooth water are not *supposed* to careen more than 7°, though it is very probable that in rolling they will heel over 7° more; in fact, in fast vessels 14° is by no means uncommon when carrying a heavy press of sail by the wind. This inclination brings a depth of side under the water equal to about one-eighth part of the ship's beam.

Now these wedges of immersion and emersion, or "the shoulders," must be accurately measured; and in a vessel of curvilinear outline the back of the wedge will have a double curvature, requiring a little judicious geometry to gauge it.

The constructor having exactly measured the volume of each of these shoulders or wedges in cubic feet, converts his measurement into tons by dividing either by 35 or 36, as the case may be; the result is one element by which to measure the power of the shoulder

VII. *Volume of out-of-water body.*

This is the volume of room in the ship above the water-line, or the surplus buoyancy, and is a material element in the safety and seaworthiness of a ship. An ordinary ship with very little of her body above the water is dangerous, because, if by accident she ships water and retains it, she will sink. When the sea runs high, the upper body is required to lift the ship over the waves, otherwise they roll over her; though sometimes (as in the monitors) it is desirable to

* One-eighth is a good proportion.

make vessels so low that the sea may run freely over them; but in this case careful provision is made that the decks are made perfectly water-tight. These vessels are, however, exceptional.

Merchant vessels have been lost by lading them so deeply that in bad weather they became easily submerged. Moreover, a vessel deeply immersed has very little lateral stability; a homogeneous body entirely immersed has none whatever; and such vessels are therefore exposed to great risk of capsizing as well as foundering. It is therefore desirable at the load water-line to note what relation the bulk of the out-of-water body bears to the under-water body, as there is a certain ratio which it is desirable neither to exceed nor to fall short of. Its volume, therefore, should be indicated by a fraction, showing that it is $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$ or any other suitable part of the under-water body.

VIII. *Volume of internal body or room in a ship.*

This is a very different element from the displacement, which measures the whole space which a ship occupies in the water, and the dead weight both of herself and what she carries. The volume now under consideration represents the void left in the inside of the hull, or the empty space. The thickness of the proposed hull has, of course, everything to do with this. Iron ships have, therefore, more room in them than wooden ones, because the hull is thinner. The hull of a 1000-ton iron ship may be reckoned throughout as about 6 inches thick,* but a wooden one of the same size may be taken at three times this thickness. A double-bottomed iron ship takes much more room off the inside than a single-bottomed one; but any well-contrived iron ship is much more roomy than a wooden one.

Roominess in merchant ships is a source of great profit, and for this reason it should be approximately ascertained at the outset. In all war vessels, *properly built*, there is generally room for more weights than the ship is able to carry; and in all designs of a ship there should be an early approximation to the proportion between the displacement (which represents the dead weight she can carry) and the volume of internal body (which represents the space she has for stowing those weights).

* This must not be confounded with the thickness of the "skin" alone, which in iron merchant vessels is seldom more than $\frac{1}{2}$ of an inch. The above includes frame, etc.

TABLE XXI.

External and Internal Capacity, etc.

Internal Capacity in tons.	External Capacity. Increased per cent. in Oak Ships.	Thickness of Sides of Oak Ships in inches.*	Thickness of Sides in Iron Ships.*
100	0.28	11	3½
200	0.27	12½	4
300	0.26	14	4¼
400	0.25	15½	4½
500	0.24	16	4¾
1000	0.20	20	6
2000	0.16	24	7

NOTE.—The proportion of external capacity to internal room must be larger in fine models and less in full models to an extent, in ordinary shapes, of five or six per cent.; but between a yacht and a collier there would be a wide disparity. The proportions above are for ordinary sailing merchantmen, and will hold good for ships that are similar.

It often happens that when this proportion is not accurately settled beforehand, a ship has a great deal of room to contain cargo without displacement enough of under-water body to enable her to carry the dead weight of that cargo; and it may also happen that she has plenty of displacement to carry more freight without having room to stow it. Mercantile tonnage, by which ships are classed, charged and chartered, is now-a-days fixed by measuring the room inside of the ship, as on this depends the "registered" tonnage placed on the register of the ship.

ABSTRACT OF THE TONNAGE LAW OF THE UNITED STATES.

The *register* of every vessel shall express her *length* and *breadth,* together with her *depth* and the *height* under the *third* or *spar* deck, which shall be ascertained in the following manner:

The *tonnage deck* in vessels having *three* or more decks to the hull, shall be the *second* deck from below; in all other cases the *upper* deck of the hull is to be the tonnage deck.

The length from the *fore part* of the outer planking on the side of the *stem* to the *after part* of the *main stern-post* of screw steamers, and to the after part of the *rudder-post* of all other vessels measured on the top of the tonnage deck, shall be accounted the vessel's length.

* See foot-note, page 167.

The breadth of the *broadest part* on the *outside* of the vessel shall be the vessel's *breadth of beam.* A measure from the under side of the tonnage deck plank, amidships, to the *ceiling* of the *hold* (average thickness), shall be accounted the *depth of the hold.*

If the vessel has a third deck, then the height from the *top* of the tonnage deck plank to the *under side* of the upper deck plank shall be accounted as the *height under the spar deck.*

All measurements to be taken in *feet* and *fractions* of *feet;* and all fractions of feet to be expressed in *decimals.*

The *register tonnage* of a vessel shall be her *entire internal cubical capacity* in tons of 100 cubic feet each, to be ascertained as follows:

Measure the length of the vessel in a straight line along the upper side of the tonnage deck, from the inside of the inner plank (average thickness) at the side of the stem, to the inside of the plank on the stern timbers (average thickness), deducting from this length what is due to the *rake* of the *bow* in the thickness of the deck, and what is due to the *rake* of the *stern timber* in the thickness of the deck, and what is due to the *rake* of the *stern timber* in one-third of the *round* of the beam; divide the length so taken into the number of equal parts required by the following table, according to the class in such table to which the vessel belongs:

TABLE OF CLASSES.

1st. Vessels of which the tonnage length, according to the above measurement, is fifty feet or under, into *six* equal parts.

2d. Vessels over fifty, and not exceeding one hundred feet in length, into *eight* equal parts.

3d. Vessels over one hundred, and not exceeding one hundred and fifty feet in length, into *ten* equal parts.

4th. Vessels over one hundred and fifty, and not exceeding two hundred feet in length, into *twelve* equal parts.

5th. Vessels over two hundred, and not exceeding two hundred and fifty feet in length, into *fourteen* equal parts.

6th. Vessels of which the tonnage length, according to the above measurement, is over two hundred and fifty feet long, into *sixteen* equal parts.

Then the hold being sufficiently cleared to admit of the required

depths and breadths being properly taken, find the *transverse* area of such vessel at each point of division of the length, as follows:

Measure the depth at each point of division from a point at a distance of one-third of the round of the beam below such deck, or, in case of a break, below a line stretched in continuation thereof, to the upper side of the floor timber at the inside of the limber strake, after deducting the average thickness of the ceiling, which is between the *bilge-planks* and *limber strake;* then, if the depth at the midship division of the length do not exceed sixteen feet, divide each depth into four equal parts; then measure the inside horizontal breadth at each of the three points of division, and also at the upper and lower points of the depth, extending each measurement to the average thickness of that part of the ceiling which is between the points of measurement; number these breadths from above (numbering the upper breadth one, and so on down to the lowest breadth); multiply the second and fourth by four, and the third by two: add these products together, and to the sum add the first breadth, and the last or fifth; multiply the quantity thus obtained by one-third of the common interval between the breadths, and the product shall be deemed the transverse area; but if the midship depth exceed sixteen feet, divide each depth into six equal parts, instead of four, and measure as before directed, the horizontal breadths at the five points of division, and also at the upper and lower points of the depth; number them from above as before; multiply the second, fourth and sixth by four, and the third and fifth by two; add these products together, and to the sum add the first breadth and the last or seventh; multiply the quantities thus obtained by one-third of the common interval between the breadths, and the product shall be deemed the transverse area.*

Having thus ascertained the transverse area at each point of division of the length of the vessel, as required above, proceed to ascertain the register tonnage of the vessel in the following manner:

* The rule for ascertaining this area is called "Simpson's" or "Chapman's" rule, and may be simplified into a formula as follows:

Area $= [A + 4\ P + 2\ Q] \times \frac{r}{3}$.

Where $A =$ sum of the first and last *ordinates.*

$4\ P =$ sum of the even *ordinates,* multiplied by 4.

$2\ Q =$ sum of the remaining (or odd) *ordinates,* multiplied by 2,

and $r =$ the common interval between the *ordinates.*

Number the areas successively, one, two, three, etc., number one being at the extreme limit of the length at the bow, and the last number at the extreme limit of the length at the stern; then, whether the length be divided according to the table into six or sixteen parts, as in classes one and six, or any intermediate number, as in classes two, three, four and five, multiply the second and every even-numbered area by four, and the third and every odd-numbered area (except the first and last) by two; add these products together, and to the sum add the first and last, if they yield anything; multiply the quantities thus obtained by one-third of the common interval between the areas, and the product will be the cubical contents of the space under the tonnage deck; divide this product by one hundred, and the quotient, being the tonnage under the tonnage deck, shall be deemed to be the register tonnage of the vessel, subject to the additions hereinafter mentioned.

If there be a *break*, a *poop*, or any other permanent closed-in space on the upper decks, on the spar deck, available for cargo or stores or for the berthing or accommodation of passengers or crew, the tonnage of such space shall be ascertained as follows:

Measure the internal mean length of such space in feet and divide it into an even number of equal parts, of which the distance asunder shall be most nearly equal to those into which the length of the tonnage deck has been divided; measure at the middle of its height the inside breadths—namely, one at each end and at each of the points of division—numbering them successively one, two, three, etc.; then to the sum of the end breadths add four times the sum of the even-numbered breadths and twice the sum of the odd-numbered breadths, except the first and last, and multiply the whole sum by one-third of the common interval between the breadths; the product will give the mean horizontal area of such space; then measure the mean height between the planks of the decks, and multiply by it the mean horizontal area; divide the product by one hundred, and the quotient shall be deemed to be the tonnage of such space, and shall be added to the tonnage under the tonnage decks ascertained as aforesaid.

If the vessel has a third deck or spar deck, the tonnage of the space between it and the tonnage deck shall be ascertained as follows:

Measure in feet the inside length of the space at the middle of its

height from the plank at the side of the stem to the plank on the timbers at the stern, and divide the length into the same number of equal parts into which the length of the tonnage deck is divided; measure (also at the middle of its height) the inside breadth of the space at each of the points of division, also the breadth of the stem and the breadth at the stern; number them successively one, two, three, etc., commencing at the stem; multiply the second and all the other even-numbered breadths by four, and the third, and all the other odd-numbered breadths (*except* the first and last) by two; to the sum of these products add the first and last breadths; multiply the whole sum by one-third of the common interval between the breadths, and the result will give in superficial feet the mean horizontal area of such space; measure the mean height between the plank of the two decks and multiply by it the mean horizontal area, and the product will be the cubical contents of the space; divide this product by one hundred, and the quotient shall be deemed to be the tonnage of such space, and shall be added to the other tonnage of the vessel, ascertained as aforesaid. And if the vessel has more than three decks, the tonnage of each space between decks above the tonnage decks shall be severally ascertained in the manner above described, and shall be added to the tonnage of the vessel, ascertained as aforesaid.

In ascertaining the tonnage of open vessels, the upper edge of the upper strake is to form the boundary line of measurement, and the depth shall be taken from an athwartship line, extending from the upper edge of said strake at each division of the length.

The register of the vessel shall express the number of decks, the tonnage under the tonnage deck, and that of the between decks, above the tonnage deck; also, that of the poop or other enclosed spaces above the deck, each separately. In every registered United States ship or vessel, the *number* denoting the total registered tonnage shall be deeply carved or otherwise permanently marked on her *main beam*, and shall be so continued; and if it at any time cease to be so continued, such vessel shall no longer be recognized as a registered United States vessel.

A ship is said to be 1000 tons burden, therefore, when she has 100,000 cubic feet of space. This is now the technical tonnage of the custom-house; but ship-owners sometimes reckon 40 or 50 cubic

feet to the ton, according to the nature of the trade that the shipper is chartering for.*

The following formula will give very nearly (within $2\frac{1}{2}$ per cent.) the register tonnage under any proposed dimensions:

Let L represent the inside *length* on upper deck from plank at the bow to plank at the stern, B the inside *main breadth* from ceiling to ceiling, and D the inside *midship depth* from upper deck to ceiling at limber-strake.

Then the register tonnage of any ship will be equal to $\frac{L \times B \times D}{100}$ multiplied by the decimal factor opposite the *class* in the following table to which she belongs:

Sailing ships	Cotton and sugar ships, *full* form	0.8
	Ships of the present form	0.7
Steam vessels and clippers	Of two decks	0.65
	Of three decks	0.68
Yachts	Above sixty tons	0.5
	Small vessels	0.45

Deduction to be made from Steam Vessels.

In every ship propelled by steam or other power requiring engine room, an allowance of space or tonnage ought to be made for the space occupied by the propelling power, and the amount so allowed should be deducted from the gross tonnage of the ship.

The rule for finding the cubical contents of the engine-room is as follows:

1st. Measure the mean length of the engine-room between the forward and after bulkheads, excluding such parts, if any, as are not actually occupied by or required for the proper working of the machinery; then measure the depth of the ship at the middle point of this length, from the ceiling at the limber-strake to the upper deck in ships of three decks and under, and to the third deck, or deck above the tonnage deck, in all other ships; also the inside breadth of the ship clear of *sponsing*, if any, at the middle of the depth; multiply together these dimensions of length, depth and breadth for the cubical contents; divide this product by 100, and the quotient

* Cargo is generally reckoned 50 cubic feet to the ton, and coal at 48 cubic feet per ton.

will be the tonnage of the engine-room, or allowance to be deducted from the gross tonnage on account of the propelling power.

2d. In the case of ships having more than three decks, the tonnage of the space, or spaces, if any, between decks above the third deck, which are framed in for the machinery or for the admission of light and air, found by multiplying together the length, breadth and depth, and dividing the product by 100, should be added to the tonnage of such space.

3d. In the case of screw-steamers, the tonnage of the shaft-alley should form part of and be added to such space after being ascertained in the usual manner.

4th. In any ship in which the machinery may be fitted in separate compartments, the tonnage of each compartment should be separately ascertained, and the sum added to the tonnage space as above.

IX. *Critical points in a ship.*

The constructor has hitherto considered certain important *areas* and *volumes* of a ship, on the mutual proportions and relations of which her qualities and powers must depend; beyond these, however, there remain certain critical *points* or *places* which are material to the whole behavior of the ship. Unless he first knows these critical points, he knows nothing about where he should place one thing or where another. *Situation* is a material part of naval construction, since masts, machinery, boilers, coals, heavy cargo, light cargo, provisions, water, guns, anchors and cables, everything, in short, that a ship is to contain and carry, as well as every particle of weight in the hull itself, may be placed either *right* or *wrong;* and even a very small weight may be so placed as to enhance some virtue or exaggerate some defect.

X. *Centres of gravity of the midship section and of the vertical sections parallel to it.*

The position of the centre of buoyancy of a ship is a material element in her behavior and qualities at sea. The place of the centre of gravity of the midship section contributes more powerfully to determine the vertical height of that centre of buoyancy than any other section of the ship, and the higher that centre of buoyancy rises toward the surface of the water the greater is the stability. Its depth below the surface when the ship is light and when

she is laden, is therefore a material element in her character; and in every trial design its place ought to be well marked.

The qualities of the ship will also be affected somewhat by the positions of the centres of gravity of the vertical sections before and abaft the midship section; and to show how these rise and fall and modify the whole, it is recommended that a line be drawn on the sheer plan, connecting all the centres of gravity of the vertical cross sections fore and aft.* This line will be instructive in showing the general character of the fore and after body, in improving the character of the midship section as regards stability or in weakening it. Where the line *rises* the stability is improved—where it *falls* it is weakened.

XI. *On the place of the centres of gravity of the water-lines.*

The places of the centres of gravity of the water-lines form elements in the determination of the place of the centre of gravity of the ship lengthwise, and they should be carefully marked on the sheer plan and connected by a line. This line of centres of gravity of water-lines will either shift *forward* as the ship goes down in the water, or shift *aft*, or remain stationary in a vertical line; if it shift aft, it will show that as the ship gets deeper and deeper in the water the heavy weights ought to be stowed aft; if the contrary, then they ought to be brought forward; if neither, they ought to be equally distributed toward both ends. Thus, the line connecting these centres of gravity becomes a permanent rule for the practical stowage of the ship, exceedingly useful to the naval officer; and ships may thus be distinguished from each other accordingly as these centres of gravity run forward or aft.

The distance of the centre of gravity, also, of each half of the load and light water-lines, on each side of the centre of the ship, from that centre, is an element in the stability of the ship.

XII. *Centre of gravity of the longitudinal vertical section.*

As this is the section which gives weatherliness to the ship and keeps her from drifting to leeward, the knowledge of the position of its centre of gravity is most important to the proper placing and arrangement of all the masts, spars, rigging and sails. This centre is the balance point of the lateral pressure of the ship on the water, and the balance point of the pressure of the sails under the wind must be

* This is called the "locus of the centres of buoyancy."

so placed as exactly to correspond with it; otherwise, if the sails and masts are too far aft in relation to this point, the ship will be *ardent,* which carried to the extreme is a very bad quality; or if they are too far forward, she will carry *lee helm,* which is a worse quality. In order to secure a perfect balance, the centre of gravity of this section and the centre of gravity of the sails (centre of effort) must be accurately obtained. In some vessels these centres must be directly over each other; but in full-bowed vessels the bluffness of bow deranges the balance, and this must be corrected by carrying the centre of gravity (centre of effort) of the sails considerably forward of the centre of gravity (centre of resistance) of the longitudinal section.*

Of course the placing of the masts is by this means regulated and determined.

XIII. *Centre of gravity of displacement or centre of buoyancy.*

This point must be found, because it is the centre (or balance point) of the whole upward pressure of the water on the ship; as, whatever may be the variety and shape of the parts of a ship, the joint power of them all, united to support a given weight, balances at this point. It has already been shown that all the weights must be so distributed as that they shall all balance each other exactly, so that the united centre of weight shall come precisely over the centre of gravity of the displacement, otherwise the ship will be pressed down out of its intended place some way or other.

The determination of the horizontal place of the centre of buoyancy is not the only thing necessary for the balance of the ship, but the vertical distance of that centre below the water-line is an element of calculation in her stability.

For these two purposes it is necessary to take as one of the elements of a ship—first, the place of the centre of buoyancy, either before or abaft the middle of length of the ship; second, the distance of this centre below the water-line. The distance before or abaft is generally reckoned in feet, and the distance below the water-lines in fractions of the main breadth. The smaller this fraction is, the greater will be the stability; for the distance of this point below the water is a measure of the tendency of the under body to upset the ship.

* In one case (a line-of-battle ship) this was as much as 15 feet. In a fine, wave-built ship, these centres go most accurately together.

XIV. *Centres of gravity of the volumes of the immersed fore and after bodies.*

When a ship breasts the sea her *fore body* is first lifted by the waves, so as gradually to raise her out of the hollow and to the top of the wave, and she then goes over the crest and pitches down the slope on the opposite side, while the fore body is raised out of the water to plunge into the ascending slope of a second wave, until the buoyancy of the fore body and the lifting power of the water again raise the bow toward the crest of the second wave, and thus lead the body over it. This pitching and 'scending is mainly done by the fore body; and in order to measure and appreciate its good or bad qualities in this respect, the position of its centre of displacement should be known.

The *after body* also contributes its share to the movement of the ship, and its action is similar to that of the fore body in many respects—with an important difference, however, due to the ordinary forward motion of the vessel. The wave strikes the bow with a force which the stern in a great measure escapes. But it is necessary to know the place of its centre of gravity of displacement also.

It is only necessary to remark here that the farther the centre of gravity of displacement of the fore body lies forward of that of the vessel, the greater will be the force with which the wave compels the fore body to rise or allows it to fall; and the same, in a less degree, holds good of the after body. It is usual therefore to state, in fractions of the length of the fore body, the distance of its centre of displacement from that of the vessel, reckoning from that centre to the forward perpendicular, and in like manner for the after body abaft to the after perpendicular.

Thus, if the fore body were pyramidal, this would be one-fourth, or 0.25; if ellipsoidal, it would be three-eighths, or 0.375; or, if wedge-form, one-third, or 0.33; and if a square box, one-half, or 0.5.

XV. *Centre of gravity of the out-of-water body of a ship and of its fore and after parts.*

These are to be found and recorded in like manner with those of the under body, and for like reasons. If these are found to correspond with those of the under-water body, the ship will have this advantage—that the fore body, in lifting its own top weight, will apply its raising force exactly under the centre of weight to be lifted

and when the under-water body supports the out-of-water body, it will apply its force directly under the weight to be raised, and by this means the straining of the ship will be the least possible.

XVI. *Centre of gravity of the internal room of the ship, and of its fore and after bodies.*

If the whole of the ship is uniformly filled with a homogeneous cargo, such as tea or sugar, coals or cotton, wool or corn, or any other uniform weight, it is plain that no discrimination or discretion can be used in stowing the weights. The cargo being all of one sort, there is no latitude for disposing heavy or light weights where it would be most proper for them to be carried; the condition is simply that the ship must be filled and take her chance. In such a ship everything depends upon the original design: if, when she is full, she is found to be badly trimmed, perhaps down by the head, or say down by the stern, it is too late to help it.

It is, therefore, indispensable that the constructor should know where the centres of weight of the internal hold, stowage and bulk of such a ship lie. He must ascertain, first, the centre of gravity of her entire internal capacity, and then of the fore and after holds; and if these fall over the corresponding centres of gravity of displacement of the ship when at her load water-line, then the cargo will exactly balance, and the trim of the ship will be perfectly maintained; if not, a difference will be manifested, which will give him the measure of how much she will be out of trim when laden. If this difference be inevitable, no remedy remains except the empirical one of putting in some ballast; and the places of these centres of gravity will be needed for the calculation of how much ballast the ship will require and where it should be placed. This is a sufficient reason why the centres of gravity of room for cargo should be calculated with the same accuracy as those of the centres of displacement, and in a similar manner.

XVII. *Centres of gravity of the "shoulders."*

When a ship heels over under the pressure of wind and sail, it is the power of the "shoulder" only that enables her to stand up under it, and therefore it is necessary beforehand to know not merely the bulk of the "shoulder" or its quantity, but the manner of its application, more or less advantageous, to sustain the pressure it is required to withstand. A given quantity of sail may be applied either

high or low on a mast,; and a given quantity of "shoulder" will require to be applied either farther away from the centre of the ship, or nearer, to suffice for this effort. The centre of effort of sail and the centre of effort of "shoulder" have, therefore both to be found and both to be measured from the central axis round which, speaking roughly, the ship has turned in heeling. This measure is generally given in feet, but the centre of the "shoulder" may also be reckoned in fractions of the half-breadth of the ship. Thus, in a wall-sided, square ship it would be at two-thirds of the half-breadth; and in a wedge-shaped ship, between one-half and two-thirds.

XVIII. *On the weight of the hull of a ship and the place of its centre of gravity.*

For the purposes of theoretical calculation merely, it is a good though rough approximation to take the whole skin of a ship, including her deck, as of a given uniform thickness and weight; and if the constructor knows from his own experience the total probable weight of such a hull, he will find it sufficiently near the truth to make a first calculation in this manner. Of course it is not true, absolutely, in any case, as scarcely ever are two ships built alike in distribution of materials; but it is sufficiently near the truth to enable the dextrous ship-builder to make it absolutely true in the *ultimate practical result* by a thoughtful distribution of all the weights of the ship as to which he has free choice.

All this will serve only for a first approximation; then, when all the details of the actual structure and equipment of the ship are finally settled, and everything placed, a final calculation must be made with great accuracy, showing the absolute volumes and weights of the hull and of its different sub-divisions, and the positions in height, length and breadth of the centres of gravity, both of figure and (where practicable) of actual weight, as well as the areas and centres of the principal planes. When this is done, the constructor will see whether his centres of gravity of displacement coincide with the position of the centre of gravity of the hull and with those of the weights which the ship is to carry, so that the ship, as a whole, as well as each part of her, may do its work perfectly, and that her trim, on going to sea, may be found to be exactly as originally intended.

When the designer has found the place of all of these points, has

measured the areas of all these surfaces, and has gauged all the volumes and capacities mentioned, he has then the elements which will enable him to judge of the qualities of his ship.

He may arrive at this judgment in two ways—either by comparing the elements thus obtained with all the similar elements of a known ship, whose good qualities he means to imitate, or he may proceed to make an absolute mathematical determination of the qualities of his ship, without reference to any other vessel.

TABLE XXII.

The Wave System of Construction, or the Elements of the Form of Least Resistance.

Lengths.

Fore body	l	Breadth	B
After body	l'	Half breadth	b
Whole body	L	Draft of water	d

Areas.

Water-line fore body	$0.5 \times B \times l.$
" after body	$0.5 \times B \times l' + 0.19635 \times B^2.$
" whole body	$0.5 \times B \times L + 0.19635 \times B^2.$
" fore body in terms of $B \times l$	0.5
" after body in terms of $B \times l'$	$0.5 + \frac{B}{l'} \times 0.19635.$
" whole body in terms of $B \times L$	$0.5 + \frac{B}{L} \times 0.19635.$
Area of midship section ⊠	$0.7854 \times B \times d$

Volumes.

Fore body	$0.7854 \times 0.5 \times B \times l \times d = 0.3927\ B \times l \times d.$
After body	$0.3927 \times B \times l' \times d + 0.13092 \times B^2 \times d.$
Whole body	$0.3927 \times B \times L \times d + 0.13092 \times B^2 \times d.$
Fore body in terms of prism of ⊠	0.5
After body " " "	$0.5 + 0.1666\ \frac{B}{l'}$
Whole body " " "	$0.5 + 0.1666\ \frac{B}{L}$
Fore shoulder	$0.1875 \times b \times l \times c.$

TABLE XXII.—*Continued.*

A wedge, the base being a circle and the outline formed by a right cylinder, standing on said circle, the other face being an ellipse touching the circle, the radius being 0.5 b, and the height c.	$0.5 \times \pi \times \frac{1}{4} b^2 \times c = 0.3927 \times b^2 \times c$.*

PLACES.

Centre of gravity of ⊠ below load water-line........................... $0.42444 \times d$.

" " fore water-line from ⊠ .... $0.2974 \times l$.

" " half-circle from ⊠ $= \dfrac{2b}{3\pi}$ .... $0.2122 \times b$.

" " after water-line from ⊠

$$\frac{0.19365 \times b \times l + 0.07854\, b^2 + 0.1487\, l'^2}{0.3927\, b + 0.5\, l'}.$$

When in this formula $l' = 1$, and $b = 0.25$, we get this distance $= 0.338\, l'$.

Centre of gravity of whole water-line before ⊠

$$\frac{0.1487\,(l^2 - l'^2) - 0.19635\, bl' - 0.07854\, b^2}{0.3927 \times b + 0.5 \times L}.$$

When $L = 1$, $l = 0.6$, $l' = 0.4$, and $b = 0.1$, this distance is $= 0.0391 \times L$.

Centre of gravity of half fore water-line from middle line........ $0.375 \times b$.

" " half-circle from middle line .... $0.5 \times b$.

" " half after water-line from middle line

$$\frac{(0.1875 \times l' + 0.19635 \times b)\, b}{0.5 \times l' + 0.3927 \times b}.$$

When $l' = 4$ and $b = 1$, we get this distance, equal to $0.395 \times b$.

Centre of gravity of the entire half water-line from middle line

$$\frac{(0.1875 \times L + 0.19635 \times b)\, b}{0.5 \times L + 0.3927 \times b}.$$

When $L = 10$ and $b = 1$, we get this distance, equal to $0.384 \times b$.

Centre of gravity of displacement of fore body before ⊠................ $0.2974 \times l$.

Centre of gravity of displacement of after body abaft ⊠

$$\frac{(0.11679 \times l' + 0.07201\, B)\, l'}{0.3927\, l' + 0.13092\, B}.$$

When $l' = 1$ and $B = 0.5$, we get this distance, equal to $0.333 \times l'$.

Centre of gravity of displacement of whole body before ⊠

$$\frac{0.11679\,(l^2 - l'^2) - 0.072006\, B \times l'}{0.3927 \times L + 0.13092 \times B}.$$

* π the periphery of a circle = 3.14 when the diameter is 1.

TABLE XXII.—*Continued.*

When $L = 1$, $B = 0.2$, $l = 0.6$ and $l' = 0.4$, we get this distance $= 0.0421 \times L$.
Centre of gravity of displacement of fore body below load water-line, $0.42444 \times d$.
" " " spheroidal body.................... $0.375 \times d$.
" " " after body,

$$\frac{(0.166677 \times l' + 0.049095 \times B)\, d}{0.3927 \times l' + 0.13092 \times B}.$$

When $l' = 2\,B = 6.2832$ and $B = 3.1416$, we get this distance $= 0.41735 \times d$.
Centre of gravity of the whole body below load water-line,

$$\frac{(0.166677 \times L + 0.049095 \times B)\, d}{0.3927 \times L + 0.13092 \times B}.$$

When $L = 5\,B = 15.7080$ and $B = 3.1416$, we get this distance, equal to $0.4213 \times d$.
Centre of gravity of fore shoulder from middle line.................... $0.5555 \times b$.
" " circular wedge.................................... $0.625 \times b$.
" " after shoulder $\dfrac{(0.10406 \times l' + 0.24544 \times b)\, b}{0.1875 \times l' + 0.3927 \times b}$.

When $l' = 4$ and $b = 1$, we get this distance, equal to $0.579 \times b$.
Centre of gravity of the whole shoulder from middle line,

$$\frac{(0.10406 \times L + 0.24544 \times b)\, b}{0.1875 \times L + 0.3927 \times b}.$$

When $L = 10$ and $b = 1$, we get this distance, equal to $0.5666 \times b$.

Centre of square fore shoulder from middle line
" " after " "
" " whole " "
} $0.6666 \times b$.

Centre of percussion of fore shoulder from middle line... $= 0.653 \times b$.
" " after " " ... $= 0.681 \times b$.
" " whole " " ... $= 0.667 \times b$.

Height of meta-centre above centre of displacement—

Fore body.. $= 0.066 \times \dfrac{B^2}{d}$

After body .... $= 0.079 \times \dfrac{B^2}{d}$

Whole body... $= 0.068 \times \dfrac{B^2}{d}$

Spheroidal body.. $= 0.0937 \times \dfrac{B^2}{d}$

TABLE XXII.—*Continued.*

MOMENTA.

Moment of square fore shoulder $= 0.6666\, b \times 0.5 \times b \times l \times c = 0.333 \times b^2 \times l \times c$.

Moment of square after shoulder $= 0.6666\, b \times 0.5 \times b \times l' \times c = 0.333 \times b^2 \times l' \times c$.

Moment of square whole shoulder $= 0.6666\, b \times 0.5 \times b \times \mathrm{L} \times c = 0.333 \times b^2 \times \mathrm{L} \times c$.

Moment of wave fore shoulder $= 0.555\, b \times 0.1875 \times b \times l \times c = 0.10406 \times b^2 \times l \times c$.

Moment of wave after shoulder $= (0.1875 \times b \times l' \times c + 0.3927 \times b^2 \times c)\ 0.579\, b = 0.10856 \times b^2 \times l' \times c + 0.2273\, b^3 \times c$.

Moment of wave whole shoulder $= (0.1875 \times b \times \mathrm{L} \times c + 0.3927 \times b^2 \times c)\ 0.5666 \times b = 0.10624 \times b^2 \times \mathrm{L} \times c + 0.2225 \times b^3 \times c$.

Substituting in these formulæ for $l = 6$, $l' = 4$, $b = 1$ and $c = 0.25$, we shall get—

For the moment of the square shoulder fore body.................... 0.5
" " " " after body.................. 0.333
" " " " whole body.................. 0.833
" " wave " fore body.................. 0.156
" " " " after body.................. 0.165
" " " " whole body.................. 0.321

Hence the stability of the fore shoulders are to each other as 3 : 1
" " after " " " 2 : 1
" " whole " " " 2.5 : 1

SKIN.

Approximate periphery of immersed ⊗ $= \frac{1}{2}\, \pi \sqrt{\dfrac{\mathrm{B}^2 + 4d^2}{2}}$.

Wet surface in terms of periphery of cylinder on ⊗ by different lengths, provided the draft remains one-fourth of the girth:

Lengths.	Fore body.	After body.	Whole body.	Lengths.	Fore body.	After body.	Whole body.
$3 \times \mathrm{B}$	.725	.789	.753	$7 \times \mathrm{B}$	.711	.736	.720
$4 \times \mathrm{B}$	.719	.765	.741	$8 \times \mathrm{B}$	.710	.731	.718
$5 \times \mathrm{B}$	.716	.752	.733	$9 \times \mathrm{B}$	.709	.726	.715
$6 \times \mathrm{B}$	.713	.744	.728	$10 \times \mathrm{B}$	.709	.722	.713

For variable drafts of water, keeping the same proportions between length and breadth, G being girth; the wet surface is equal to $\mathrm{L} \times 2d + \mathrm{L}\,(\mathrm{G} - 2d) \times$ by the following fractions.*

Lengths.	Fore body.	After body.	Whole body.	Lengths.	Fore body.	After body.	Whole body.
$3 \times \mathrm{B}$	.45	.578	.506	$7 \times \mathrm{B}$	.422	.472	.440
$4 \times \mathrm{B}$	.438	.530	.482	$8 \times \mathrm{B}$	.420	.462	.436
$5 \times \mathrm{B}$	.432	.504	.466	$9 \times \mathrm{B}$	.418	.452	.430
$6 \times \mathrm{B}$	.426	.488	.456	$10 \times \mathrm{B}$	.418	.444	.426

* For fore or after body L becomes l or l'.

CHAPTER XXIV.

SHIPS FOR WAR.

A MAN-OF-WAR, in general structure, may differ from a merchantman either very little or very much. A first-class clipper differs very little either in size, proportion, shape or qualities from a fast-sailing frigate of equal tonnage; it is mainly in the interior arrangement, fitting and equipment that they differ. Both equally require that the design of the hull shall be stable, weatherly, fast, easy and handy, and that their structure shall be stout and staunch, and that their driving power shall be such as to give them the speed required. The constructor, then, need only consider the points in which their purposes require that they should differ.

As the purpose of the merchantman is to carry freight and earn profit, so the object of the man-of-war is to fight and achieve victory. Power to destroy takes the place of power to carry; but just as carrying power does the merchant no good if it does not earn profit, so fighting power does the nation no good if it does not win victory, since to win is the work of both. The question, therefore, which underlies the whole design, construction and equipment of a man-of-war is how to win a victory? What are the points, then, in a man-of-war which will enable her to win a victory?

The first point after *seaworthiness* is, that she has the *speed* to find her enemy, since, otherwise, she may never find, and, consequently, never fight her adversary.* When the enemy is found, the commander must have the power to choose his *time* to fight, for choice of *time* and *place* in an action is half the victory. *Speed*, then, is the first condition of victory.

* It will be remembered by the readers of naval history that much of Nelson's time was lost in fruitlessly endeavoring to find the French fleet, which at that day was vastly superior to the English fleet in point of *speed*.

If what has just been said is true of an action between ship and ship, it is much more true of a fleet; therefore, all the ships composing that fleet should, without exception, have the same uniform highest rate of speed, otherwise it will not be the admiral who chooses time and place for the battle, but it will be the slow ships that decide. The presence in the fleet of a few slow vessels may be enough to lose him the battle.

The next point essential to victory is choice of distance. Whether he shall engage at long or short range often decides the fate of an action. The fast ship can, if she chooses, keep at long range out of the way of the shot of her enemy, and destroy that enemy by her guns of longer range if she possesses them. If, on the contrary, it is the enemy which has the longer range, the fast ship can destroy the inequality of range by coming rapidly to close quarters with her adversary; so that, in either case, the slow ship is nearly in the power of the fast one. The fast ship and the fast fleet then command the victory.

The next point after speed is *steadiness.* A ship of-war must be regarded as the platform of a floating battery; if this platform be steady, her guns may aim true and deliver destructive fire; if not, they fire wildly and do little execution; and to waste ammunition is to fail. A stable platform in a ship of war is one of the highest achievements of naval science. An unstable platform is caused, sometimes, by an undue balance of weights in the ship, which gives her spontaneous rolling motion; sometimes by a form which gives her a tendency to adapt herself to every change on the surface of the sea. But a ship may be constructed so as to give the sea the least power over her, either to make her roll or pitch.

The fine ends of the wave system accomplish the one, the round, tumble-home side accomplishes the other; so that as to a ship's own tendency to roll, a low meta-centre and a low centre of gravity* do all that is possible to prevent *that.*

The wonderful combination of ease with stability and steadiness of platform which distinguished the old French vessels of M. Sané is to be attributed to the success with which he gave effect to the tumble-home side, low meta-centre and low centre of gravity.†

* This, of course, refers to the centre of *weight,* not to the centre of buoyancy.

† The U. S. frigate "Constitution" was also a notable instance of this; very few ships built since have exceeded her in these qualities.

Stability of platform and consequent steadiness are another condition of victory. If, in a given sea, one vessel delivers her fire with sure and steady aim, and the other fires wildly, victory cannot long remain matter of doubt.

As size of ship has everything, in a merchantman, to do with quantity of cargo, so the size of a ship has considerable to do with successful action between men-of-war of the broadside pattern. The odds are in favor of the larger ship. This is untrue in one sense and true in another. It is taken for granted that the larger the ship the heavier the battery; and it is by the weight of the broadside she can deliver in a given time that the power of a ship of war is measured. Between two ships, then, of different size, it must be supposed that the weight of the broadside is proportioned to the size of the ship, or that the greater tonnage carries with it the heavier armament and the larger ship's company to work it. This being so, the victory will be on the side of the larger ship.

Power of battery is, therefore, the next element of victory, and the best ship is that which can carry and work the most powerful battery. But now the question arises, What shall be called the most powerful battery? Shall it be the greater number of guns, the greater size of the guns or the greater weight of broadside? It is now generally admitted that victory lies with the larger guns and the heaviest broadside, and that a number of guns of small calibre are worthless.

The basis of construction, then, of a man-of-war, may be said to be the weight of armament she is to carry and the speed at which she is to carry it, just as in the merchantman, it is the weight of cargo she has to receive and the speed at which she has to deliver it; the object of both being to carry a given weight to a given place. But the difficulty with a man-of-war is, that she has to carry her weights in the wrong place; the merchantman carries her weight in her hold; the man-of-war has to carry hers on her decks. The deck of the man-of-war is her battery platform, that her guns may be carried well out of the water, which is an obvious condition (except in certain peculiarly built vessels)* of fighting them successfully. Men-of-war with a low gun deck must shut their ports in a heavy sea, and that deck is then useless. The loss of the lower gun deck in an old-fashioned

* The "Monitors" for instance.

line-of-battle ship was only a partial disarmament, but in the modern ship it is total defeat.

The armament to be carried and the height at which it is to be carried must first be settled, then, and this may be called the ruling condition of the modern fleets of the broadside type.*

The weight of the heaviest broadside ship of to-day may be taken at 50 guns, of say 12 tons each, or 600 tons of weight carried in a single tier at 9 feet, or in a double tier at 13 feet. This is the problem that English and French constructors have had to solve.

Next comes a new condition of naval construction arising out the modern invention of iron armor. You can destroy the enemy if your ship has the speed to catch him, and battery enough to smash and sink him; but an important question remains—your powers of *endurance* and his. Therefore power to endure the enemy's fire is next in value to the power with which you deliver your own broadside. The assistance of iron is therefore sought. With iron armor the ship may endure the enemy's battering; and in this case *power of endurance* is ultimate and sure victory.

The endurance of iron armor is found to consist in *two* qualities, and only two—*weight* and *toughness.* Without weight in the armor it is impossible to stop the moving weight in the shot, and without toughness it is impossible to arrest its speed. The weight of the armor struck diminishes the speed of the motion communicated to it; and the toughness of the armor serves to spread the motion around the point struck, and to extend this motion forward along with the ball, so as to retain hold of it with most force through the longest time. This is the whole virtue of armor. Light armor is of no use, because, in proportion to its lightness, it receives more motion, while rigid or hard armor cannot spread the impact of the shot and keep hold of it long enough to arrest it. Hence all sorts of shapes of thin armor, as well as all attempts to use armor of hard steel or unplastic iron to arrest the shot, have failed. The part of the armor struck by a round shot has to be at least as heavy as the shot itself to keep it out, and at least so tough as to spread the blow over an area two or three times its own diameter, and be able at the same

* The old style was 4 and 5 feet out of water; 6 to 7 is the height of the ports of the ships of the French navy; 8 to 9 of the ships of the British navy; 11 feet was the height of the United States steam frigate "Merrimac's" midship port.

time to yield and bear, without fracture, an indent nearly the thickness of the plate itself. These qualities attained, the armor is shot-proof. Experience teaches that armor should be *two-thirds,* at least, the diameter of the round shot fired at it, while it should be of the toughest and most plastic material that can be produced.*

Yet, when cylindrical bolts can be fired with the same velocity as round shot, still heavier armor and new conditions will be required to resist it, and there will still remain this question, Whether the punched holes of the rifled shot will do greater harm than the battering and punching power of the heavy round shot like the 15 and 20 inch. The problem of endurance may, however, be considered as solved when ships can be coated with armor which hardened spherical shot of the above calibre, fired with an initial velocity of 1500 feet per second, cannot pierce.

Power of endurance, therefore, is bound up in these three things: weight and quality of armor, and weight and speed of shot, with which also go weight and size of gun. For the purposes of naval construction it may be given, as a general rule, that the thickness of the armor should be at least two-thirds the diameter of the spherical shot, and the gun about a hundred times the weight of the shot.

The 8-inch shot will have to be stopped with 5½-inch armor, the 9-inch shot with 6-inch armor, the 12-inch shot with 8-inch armor, the 15-inch shot with 10-inch armor, and the 20-inch shot with 15-inch armor. These are the conditions of endurance to be met at present.

But armor to a ship, like armor to a soldier, is plainly an encumbrance and embarrassment as well as a defence. It is a great weight to carry; it is top weight, and therefore hard to carry; it is winged weight, and therefore slow to move, but hard to stop when moving. Armor, then, adds a new difficulty to construction, of the same nature as a heavy battery of guns—with this addition, that it is much greater in quantity.

For example, the armament of the side of one of the English iron-clads for a single gun only, when 5 inches thick, weighs 30 tons: and if a two-decker, 20 tons for each gun. It is plain, therefore, that the ship which was able to carry 5-ton guns on its deck may be quite unable to carry those guns with the addition of 20 or 30 tons

* The Sheffield, Lowmoor and Pittsburg works produce this kind of iron in great perfection.

of armor for each gun; and assuming that a 15-ton gun is the future armament of a broadside ship, she will have to carry with each of these guns 60 tons of armor, if a single decker, or 40 tons of armor if a double decker!

These considerations enable one to understand and measure the work to be done by an iron-plated armor ship. If her guns be light and numerous, and her armor thin, she may be able to carry it over her whole length, with only so much additional breadth as suffices to carry the weight of armor and armament in respect to buoyancy and stability; but when the weight of the guns and the thickness of the armor are increased so much that the dimensions to which the constructor may be limited are inadequate to carry them, he has to begin afresh and seek new conditions of structure.

It is thus that the partial battery system has grown out of extreme weight of battery and of armor, the size of a ship being limited by the narrowness and shallowness of the channels it has to navigate, and by seagoing qualities.*

If therefore, the constructor has a given length, breadth and depth, it is clear that these dimensions limit the power of the ship to the weight of guns and armor she can carry; and it is no longer a question, as in the old wooden ships, of carrying her battery or gun platform along her broadsides from stem to stern. So many guns and so much armor as she can securely carry she may take, and to that quantity she is limited by the conditions of her existence. These conditions have given rise to the modern system of partial batteries, of which the "Ironsides" of our service, the "Warrior" and "Achilles" of the English navy, and the "Magenta" and "Solferino" of the French navy are instances.†

Necessity, therefore, and not choice, has been the origin of the partial-battery system; and officers of the old school, who regret the continuous batteries of bygone wooden fleets, should remember that it is simply impossible to carry a greater weight higher out of the water with stability and seaworthiness than the *laws* of nature will admit.

* Docks and harbors sometimes limit these dimensions; but it is less costly to alter docks or dredge harbors than to have a fleet overmatched and defeated; and it is agreed that the whole question is one of gaining victory.

† The "Warrior's" gun platform occupies only 220 feet of her length; the "Solferino's" double-tier gun battery only 150 feet of her length; the "Bellerophon's" and the "Ironsides'" only 150 feet on a single deck.

An important consideration belonging to the partial-battery system is the great stability of platform and admirable sea qualities which arise from the concentration of great weights on the central body of the ship, instead of carrying them out to the ends.

To a modern fast screw steamer fine ends are indispensable. To cover these fine ends with heavy armor and broad gun platforms is to produce in every way a bad seagoing ship. No more armor must extend toward the ends than is indispensable for the ship's endurance; and therefore it is enough that it be carried up to the first deck out of water, and as far forward as the ship needs protection; this done, the armament and armor should be concentrated in the centre, where the middle body has power to support them, and where action of the sea on the ends of the ship will not much disturb their stability. The battery thus concentrated in the middle, the extremities of the vessel may serve for all that accommodation for officers and crew which can only be well given where there is plenty of room, light and air; and it is only this system which can thus combine in the same ship an impregnable fortress in the centre, and *a roomy, well-ventilated home* in the two ends. The partial-battery system, therefore, seems the best solution of the problem of heavily-armed, iron-clad, distant-cruising, speedy and seaworthy ships.

The form, therefore, which the problem of modern naval construction takes is this: Such a length of ship as will enable her to attain the speed necessary to catch her enemy, choose her time and place of action, and fix her own distance for engagement. The dimension of her breadth will next be fixed by the height at which her gun platform must be carried above water, while the number of guns which that platform must contain should be limited entirely by the quantity she can *steadily* sustain. The partial battery thus becomes a fortress, within which must be included whatever is most vital and valuable—guns, ammunition, engines and boilers.

One of the forms of partial battery is the circular form or revolving turret, which deserves a separate notice, since a kind of rivalry has arisen between it and the fixed partial battery; but in reality there is no antagonism, both being parts of the same system, capable of being used together or separately under peculiar circumstances, to which either is the better fitted. The case to which the revolving turret is peculiarly suited is this: A ship has not always the power

of running close to her enemy and sustaining his fire with closed ports until she is fairly alongside and ready to deliver a broadside. The case is frequently that of her having to chase an enemy, outmanœuvre him or pass a battery through a sinuous course or tortuous channel. In such a case there occur many positions of the ships where broadside guns are of no avail, not having the lateral training sufficient for the purpose.

The revolving turret has therefore the following advantages: It supplies a convenient and easily-handled mounting for a very large gun; it has machinery which enables that gun to be worked with a very small crew, trained with the greatest ease, and aimed with the greatest exactness round any number of degrees of a circle, so that its aim may be at all times independent of the course of the vessel; and it secures these advantages with a very small opening of port, and therefore with comparative safety to the gun's crew, by carrying round with the gun, on the same revolving platform, a complete shield of armor. It is, in short, a revolving round-tower, containing a couple of guns, or a single gun, on parallel fixed platforms on the inside—these guns having no lateral train of themselves, but merely elevation and depression. The training is done by machinery, with steam from the boilers, which carries this turret round a centre-balancing pivot or *spindle* directly over the keel of the ship.

The word of command diverts the turret to the right or left, slow, quick or stop; while the captain of the gun stands, lock-string in hand, with his eye on the sight, ready to fire at the instant his gun bears upon the enemy. A trial of this arrangement through a great war has convinced most officers that this is the perfection and luxury of gunnery.

But the turret system is valuable only in special cases. It enables a vessel to carry a greater weight of iron to protect her guns and hull; on the other hand the guns are few in number, and their fire extremely slow. The turret ship cannot afford to throw away a shot, and must come to close quarters to fight; and unless she possesses *great speed*, this cannot be done. For the defence of a coast line, and for close action in which ship is pitted against ship, actual war has proved the turret system to be the better of the two. For the reduction of forts and batteries, and for distant and lengthened cruises, the broadside system has the advantage.

The operations against Charleston and the reduction of Fort Fisher, during our late war, abundantly proved the merits of the two systems, as illustrated in the case of the "Monitors" and "New Ironsides." The views here expressed are not therefore exclusively partisan to either system. The following, however, is a plan which, it is thought, combines the advantages of both:

When the number of guns is small, say four, and the ship is of sufficient size conveniently to carry them, let her carry four guns in two turrets, and use both systems together. Place two turrets, one in the after body and one in the fore body, afore and abaft the engine-room; then enclose the whole space on deck between the two so as to form a broadside battery: the bow turret might sweep 270° of the horizon, the stern turret the same; and in addition to the turrets in the ship, with 60 feet of engine-room, have a broadside of four guns, or eight in all on each broadside; the whole length of battery not to exceed 120 feet of the centre of the ship.

The protection of boilers, magazine and machinery and the deck immediately under the feet of the gun's crew is by far the most *important* feature of protection. The protection of the gun's crew or of the battery is not so important for the following reasons: Naval action with long-range guns will commence as soon as the ships are within range of each other, and will probably conclude before coming to close quarters. It will, therefore, be the destruction of the ship rather than the slaughter of the crew which will decide the battle. The ship's hull, as a whole, will be the target aimed at; therefore, the men will be quite ready to fight their guns as of old without personal protection, provided the deck on which they stand is made safe.

For a multitude of purposes, fleet cruisers with partial protection and great speed would be most useful. They need never be reckoned as ships of the line-of-battle, nor take higher rank than fast cruisers. They could always choose *when* to fight and *when* to avoid action. They would never be expected to lay alongside of shot-proof batteries, as they could render more important service without the chance of entailing national discredit.

Much has been said of protecting the water-line of a ship, as if the water-line was something tangible and defined. The water-line in a sea-way is just what the fancy of the sea and stress of weather choose to make it—an abstraction, not a reality. The whole thin part of

the bow and stern are liable to be out of water. Protection of a water-line is, therefore, a fictitious element of safety against the gunner who watches his time to deliver his shell near the bow or stern of his enemy's ship the moment the wave leaves the stern or bow bare. The only protection thin, fine ends can receive is the sub-division, horizontally, vertically and longitudinally, by bulkheads—forming water-tight compartments.

Having decided upon the quantity of armor to be carried, this sub-division into water-tight compartments becomes the great element of safety and endurance. It gives the means of sustaining damage to the hull for the longest time with the least danger.*

To the utmost then, even at the loss of some convenience, the interior of the ship should have transverse bulkheads, longitudinal bulkheads and iron decks, *all water-tight;* air-tight even, if possible.† The contents of all spaces should, to a great extent, be carried as it were in tanks. All openings for ordinary accommodation should have water-tight iron hatches, covers and doors; and closing all these openings would be the first preliminary to action. Powerful steam pumps should also be furnished as a necessity for casualty.

An iron-clad vessel without such minute sub-division is not only liable to be sunk, but long before that is liable to overturn from diminished stability; while an iron-armored ship, with these provisions for action ably carried out, may be regarded during a protracted action as equally proof against artillery, water and fire.

* Water-tight compartments have not proved very successful in wooden ships. In iron vessels, however, the contrary is the case.

† The iron-cased ships of the British navy are admirably protected in this way.

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TABLE XXIII.

Iron-clad Fleet of the United States Navy during the Recent War.

CLASS.	No. Built.	DIMENSIONS. Length on Deck.	Beam of Iron Hull.	Beam Extreme.	Draft of Water.	Height out of Water.	Tonnage.	No. of Turrets.	Inside diameter of Turret.	Height of Turrets.	No. of Guns in each Turret.	No. of Cylinders.	Length of Stroke.	Diameter of Cylinders.	Indicated horse-power.	INTENDED SPEED.‡
		feet.	ft. in.	ft. in.	ft. in.	ft. in.			feet.	ft.			ft. in.	in.		
Puritan	1	351	41.8	50.	21.0	1.6	3265	2	26	9	2	2	3.0	100.	4560	15 knots.
Dictator	1	320	41.8	50.	21.0	1.6	3000	1	26	9	2	2	4.0	100.	4500	15 knots.
Passaic	8	200	37.8	45.	9.6	1.0	840	1	21	9	2	2	1.10	40.	400	7 knots.
Tippecanoe	9	224	37.6	43.	11.6	1.3	1034	1	...	...	...	2	2.0	48.	1000	$9\frac{1}{2}$ knots.
*Shawnee (2 screws)	20	225	33.0	45.	7.0	1.0	614	1	21	9	2	4	2.6	22.	600	9 knots.
Original Monitor	1	173	36.2	41.6	10.0	1.6	......	1	20	9	2	2	1.10	40.	400	6 knots.
Shackamaxon (2 screws)	4	345	wood.	56.8	......	.....	3130	2	...	...	2	...	.....	.....	......	15 knots.
Monadnock (2 screws)	4	270	wood.	52.10	13.0	1.3	1560	2	...	...	2	...	.....	.....	......	10 knots.
Onondaga (2 screws)	1	226	47.0	51.2	11.6	1.0	1250	2	...	...	2	...	.....	.....	......	$9\frac{1}{2}$ knots.
†New Ironsides	1	220	......	60.0	13.0	20.0	3296	...	...	...	...	...	.....	.....	......	7 to 8 knots.

* This class, known as the "Light drafts," proved to be complete failures, and being built upon, were turned into torpedo vessels.

† The "New Ironsides" carried a powerful broadside battery of 14 XI-inch guns, 2 100-p'drs and 2 60-p'drs (rifles.)

‡ With the exception of the "Monadnock," few of these vessels ever attained their intended speed.

TABLE XXIV.

Armament of Ships in the United States Navy during the Recent War.

First Rate,
(as Minnesota.)

1 150-pounder rifle..
1 XI-inch............ } in pivot.

42 IX-in. smooth bore
4 100-p'dr rifles......
4 howitzers........... } in broad-side.

Second Rate,
(as Brooklyn.)

2 100-p'dr rifles........ in pivot.

20 IX-inch, smooth..
2 60-p'dr rifles.......
2 howitzers........... } in broad-side.

Third Rate,
(as Eutaw.)

2 100-p'dr rifles......... in pivot.

4 IX-inch, smooth...
2 24-p'dr howitzers..
2 20-p'dr rifles........ } broad-side.

Fourth Rate (a),
(as Marblehead.)

1 XI-inch smooth (pivot).
1 20-p'dr rifle "
4 24-p'dr howitzers (broadside).

Fourth Rate (b),
(as Nipsic.)

1 150-p'dr rifle.......
1 30 " " .... } pivot.

2 IX-inch.............
4 howitzers............ } broad-side.

Iron Clads.

New Ironsides { 2 100-p'dr rifles. 2 60 " " 14 XI-inch.

Monadnock ..... 4 XV-inch.

Montauk ..... { 1 XV-inch. 1 150-p'dr rifle.

Onondaga.... { 2 XV-inch. 2 150-p'dr rifles.

Mississippi Gunboat (iron-clad),

3 IX-inch.
4 VIII-inch.
2 100-p'dr rifles.
1 50-p'dr "
1 30 " "

Powers of Ordnance.

	In shot. lbs.	In shells. lbs.
1st rate................	2606	2123
2d "	1220	990
3d "	424	343
4th "	210	183
	294	255
IRON CLADS.		
New Ironsides......	2584	2157
Monadnock...........	1764	1320
Montauk..............	606	465
Onondaga	1180	930
Mississippi gunboat	588	480

TABLE XXV.—*English Iron-clad Fleet.*

	Class I.	Class II.	Class III.			Class IV.			Gunboats.			
	Ship-of-the-line.	Frigate of "Warrior" class.	Corvette of "Bellerophon" class.	Corvette with Two Turrets.	Corvette.	Corvette with minimum protection.	Iron Corvette without protection.	Partial Battery Corvette.	Class I.	Class II.	Class III.	Wave-form Turret Vessel.
Length on load water-line, in feet	402	380	300	285	300	251	250	270	138	140	100	175
Breadth extreme, in feet	68	58	56	52	48	40	40	40	25.5	23	22	25
Depth at side, in feet	50	36	38	33.5	33.5	18	18	17	14.5	9.5	8.	12.5
Mean draft of water, in feet	28	20	24	24	20	12	12	12.5	10.5	6.75	4.5	8
Tonnage (builder's)	8,834$\frac{74}{94}$	6,212$\frac{42}{94}$	4,246	3,557	3,201$\frac{8}{94}$	1,906$\frac{36}{94}$	1,906$\frac{36}{94}$	2,076$\frac{56}{94}$	417$\frac{44}{94}$	350	217	553
Height of lower portsill above load water-line, in feet	9	10	9.5	17	8	10*	10*	6.5	8.5*	8.5*	7.5*	7.
Area of immersed midship section, in square feet	1,617	1,000	1,075	1,078.66	820.14	390	367.20	428.18	208	114	95	140.
Area of load water-line, in square feet	21,360	17,889	13,440	11,963.54	11,134.65	7,160	6,369.96	8,068.84	2,553	2,500	1,794	2,625
Tons per inch of immersion	51	40	32	28.48	26	17	15	20	6	6	4.5	3.
Displacement, in tons	12,738	7,256	7,000	5,666	4,741	1,950	1,700	2,218	504	340	211	450
Thickness of armor plates, exclusive of backing, inches	5	4.5	6	4.5	4.5	4.5	....	4.5	4.5	4.5	4.5	....
Weight of hull of vessel, in tons	4,400	2,500	1,500	2,800	1,280	724	724	800	170	135	82	200
Weight of total armor, inclusive of bulkheads, in tons	2,500	2,297	2,000	810	1,550	300	....	650	100	50	47	64
Weight of engines, boilers and water, in tons	2,000	1,000	1,000	600	800	355	355	355	75	45	21	75
Weight of guns, ammunition, etc., in tons	720	400	200	280	250	125	125	125	50	25	12.5	12.5
Weight of equipment, stores and fuel, in tons	2,300	1,100	1,250	1,023	660	412	462	364	97	90	36	80
Number of men	900	600	600	300	400	400	400	400	....	....	....	....
Nominal horse-power of engines	2,000	1,250	1,000	800	1,000	500	500	500	100	60	30	100
Depth of centre of gravity of all the weights below load water-line, in feet	3.23	—1.0	....	....	2.63	1	4	0	0	0	....	....
Depth of centre of gravity of displacement below load water-line, in feet	12.	7.42	10.5	9	8.94	5.16	5.5	5.5	4.1	2.5	2	3.5
Height of meta-centre above centre of displacement	14.26	16.72	13.61	....	11.15	13.65	13	12	6.43	9	9	9
Height of meta-centre above centre of gravity of weight	5.49	8.30	....	....	4.84	9.49	12.5	6.5	2.33	6.5	....	....
Number of guns, protected	76	26	20	4	20	....	....	10	....	2 partial	1 partial	1 turret
Total number of guns carried	90	40	20	4	20	10	10	10	4	2	1	1
Speed in knots, over measured mile	14	14	13	13.5	13	12 to 13	16 to 17	13	9	9	6 to 7	12
Depth of armor below load water-line, in feet	5	5	5	5	4	4	....	6	3.5	2.5	1.5	....

Class I.—A ship-of-the line, iron-clad. Class. II.—A frigate of "Warrior" class, with lighter draft.

Class III.—The third column in this class is a vessel having all her guns, magazine and engine-room protected. She carries 18 broadside guns on her lower deck, the 2 fore and aftermost ones being able to fire in a line parallel to her keel. She is further able to carry 4 guns more, 2 forward and 2 aft, in shot-proof batteries on upper deck.

Class IV.—The first vessel in this class has only her two magazines, engine and boilers protected. She is able to carry a large quantity of canvas. The second vessel, or the "Alabama" class, is a fast clipper ship without any protection; she carries a very large quantity of canvas; her 10 pivot guns, when not in action, are housed in pairs, fore and aft along centre of the deck; 4 on each side are able to fire in a line nearly parallel to the keel; the hull being comparatively low, she is a difficult target to hit.

* In Class IV., and all the classes of gunboats, the height of the lower portsill above the water-line has been given as height of centre of muzzle of gun above the water-line, these vessels having no ports.

TABLE XXVI.

Principal Dimensions of some Fast River-Steamers in the United States.

NAME.	Length.	Breadth of Hull.	Depth at side.	Draft.	Breadth over the Guards.	Area of ⊠ Section.	Diameter of Cylinder.	Length of Stroke.	Diameter of Wheel.	Breadth of Wheel.	Number of Boilers.	Diameter of Boilers.	Length of Boilers.	Heating Surface.	Grate Surface.	REMARKS.
Eastern Navigation.	ft.	ft. in.	ft. in.	ft. in.	ft. in.	sq. ft.	in.	ft.	ft. in.	ft. in.		ft. in.	ft. in.	sq. ft.	sq. ft.	
Alida	265	30.0	10.0	......	......	......	50	12	31.6	9.6	......	......	......	....	......	Low-pressure condensing engines.
Bay State	300	29.0	12.6	......	......	......	76	12	39.0	10.0	......	......	......	....	......	
Thomas Powell	225	28.6	9.0	......	......	......	48	11	......	......	......	......	......	....	......	
New World	375	36.0	10.6	......	69.0	......	76	15	45.6	......	......	......	......	....	......	
Daniel Drew	244	31.0	9.3	4.6	......	126	60	10	29.0	9.0	2	8.0	29.0	3,350	105	
Elm City	280	35.0	11.0	5.6	......	175	65	12	34.6	9.0	2	11.0	32.6	3,556	162	
Francis Skiddy	322	38.0	10.0	7.6	......	245	70	14	40.0	11.0	4	8.0	28.1	5,132	208	
Metropolis	325	45.0	15.0	10.6	81.2	375	105	12	40.0	13.0	4	11.3	20.8	12,000	......	
Plymouth Rock	330	40.0	13.0	6.0	......	220	76	12	37.0	10.0	......	12.6	38.0	....	......	
Commonwealth	316	41.2	13.6	8.4	77.0	......	72	12	38.0	......	2	12.3	38.0	5,000	......	
Newport	350	44.0	15.0	10.6	80.0	350	105	12	42.0	13.0	4	11.3	20.8	12,000	......	
On the Western Waters.																
Eclipse	360	42.0	8.0	5.0	......	200	36	12	40.0	15.0	......	......	......	....	......	High-pressure non-condensing engines.
Altona	245	31.0	6.0	3.0	......	90	26	8	32.0	......	......	......	......	....	......	
J. M. White	250	30.0	9.0	......	......	......	30	10	30.0	14.0	......	......	......	....	......	
Buckeye State	260	29.0	7.0	4.0	......	110	29	8	31.8	12.0	5	42.0	30.0	....	......	
Memphis	260	38.0	8.0	4.0	70.0	150	26½	8	32.0	13.0	4	44.0	30.0	2,430	76	
New Jeannie Deans	240	39.0	8.0	4.0	......	155	24	7	26.0	13.0	4	46.0	25.0	....	......	
Paragon	225	38.0	8.0	4.6	70.0	150	29	8	34.0	14.0	6	40.0	28.0	....	......	

CHAPTER XXV.

DRAWINGS AND MODELS.

It is absolutely necessary, in order to *scientifically* construct a vessel, that the designer, whether owner or builder, should thoroughly understand ship drawing.

The first process toward building a properly-constructed vessel is to make accurate drawings of her on paper upon a reduced scale. From these drawings other drawings are made or "laid off" upon the mould-loft floor. From these last-mentioned drawings in chalk, moulds of thin deal are made, and by the help of these moulds the timbers composing the "frame" of the vessel are cut out and the frame put together.

The drawings from which a ship is constructed are three in number:*

1st. The *sheer plan*, containing a series of longitudinal vertical sections.

2d. The *half-breadth plan*, containing a series of longitudinal transverse sections.

3d. The *body plan*, containing a series of transverse vertical sections.

The student should begin by copying a set of drawings, which is quite easy. Like other arts, it requires a little practice, but after a few attempts he will become dextrous in the use of the irregular curves, battens and drawing pen. There are three methods of copying:

First. By a tracing of the original on prepared transparent paper or muslin placed over it.

Second. By placing the original plan over a sheet of paper and pricking the principal points through with a fine needle, so as to mark the lower sheet; guided by these points, the draughtsman can fill in the detail, a little practice only being necessary, and an expert draughtsman requiring but a few points. Care must be taken to hold the needle upright.

* See drawing of the schooner yacht.

The third plan is to measure the principal points with a pair of dividers or a scale, and to transfer these points to the copy: this is the best method for the student. After copying one or two drawings in this manner, he will become acquainted with the connection between the different lines in the plans. Some draughtsmen stretch their paper on the drawing board by the sponging process, which presents an excellent surface for drawing on; but when cut from the board, the paper *invariably contracts*, and therefore the drawing will be more or less inaccurate according to the extent of this contraction.

The best method is to hold the paper to the board with "thumb tacks." Suppose, then, that the student is to copy a ship drawing. It is only necessary to describe the order in which the lines should be copied, the connection between them and the method of ending them.

As a general rule, the lines representing the actual parts of the vessel are drawn in *black;* the water-lines or horizontal sections below the load water-line in *green*; those lines which are not part of the vessel, but are of use in making the drawing, in *ticked black;* and the inboard work or profile in *red* ink.

The light is supposed to come from the *right*-hand *upper* corner of the paper, and consequently the upper and right-hand sides of a solid are represented by *fine* or thin lines; those on the lower or left hand, by *thicker* lines: thus, the lower side of the keel is thick, the fore side of the masts are thin, etc. The drawing should be completed *in pencil* before ink is used.

The *middle line* of the *half-breadth plan* is first drawn, and from this line, as a *base,* all breadths are measured perpendicular to it; first, the foremost perpendicular is drawn, and then, at their proper distances, the lines corresponding to the other vertical sections.

The *load water-line* of the *sheer plan* is drawn *parallel* to the middle line of the half-breadth plan, and consequently the sections are vertical to it.*

From the load water-line all *heights* and *depths* are measured; it is therefore the *base* of the *sheer* and *body plans.* The *rabbet line* and lower side of the keel in the sheer plan are next drawn; the interme-

* This, however, is not always the case, for sometimes the upper edge of the rabbet of the keel is made the base of the sheer and body plans, but where there is much difference in the draft of water forward and aft, the load water-line is preferable.

diate water-lines are sometimes drawn parallel to the load water-line, and sometimes at equal distances between it and the rabbet line of the keel: in the former case there is less trouble in transferring the heights to the body plan; in the latter they are better adapted for making the calculations.

The several *sheer lines* must next be set off, the heights taken from the water-line on each section, and a *penning batten** made to pass through the points, and a line drawn along the batten.

The *stem*, *rabbet of stem*, the *stern-post* and its *rabbet* are next in order. The *counter* may be copied by drawing in the original a continuation of the rake of the counter through the water-line to some other line below it; this line, transferred to the copy, will give the rake of the counter. The detail of this part is then easily filled in.

The different half-breadths of the water-lines and of the sheer lines must next be transferred from the original, and a thin batten "penned" to pass through the points in each section. Some practice and considerable patience are necessary in using the penning battens and weights on it; if the batten is too pliant, the line may not be a fair curve, and if too stiff, it is difficult to confine it in its proper position.

The *endings* of the sheer lines and water-lines in the half-breadth plan are obtained by squaring down from the sheer plan the intersection of each line respectively with the fore edge of the rabbet of the stem, or the after edge of the rabbet of the stern-post, as the case may be, to the middle line of the half-breadth plan, and from these spots set off from and perpendicular to the middle line *half* the *siding* of the stem or stern-post at the respective heights; these latter spots will be the endings required.

The middle line of the body plan, or fore perpendicular, is drawn square to the base, and the *half siding* of the stem and stern-post on each side of it. It is usual to make the base of the sheer and body plans in one line, and therefore, when the load water-line is the base, a continuation of it from the sheer plan will be both the base and the load water-line of the body plan also. When the other water-lines are parallel to the base, they may also be continued, but when not parallel the distance of each water-line from the base must be trans-

* This should be made of whalebone or lancewood, and used with small weights to keep it penned in place.

ferred from the sheer to the body plan. Lines drawn square to the middle line at these heights will represent the vertical height of each water-line at each section in the body plan, and on these lines the respective half-breadths, taken from the half-breadth plan, must be set off from the middle line; the several sheer lines are transferred in a similar manner. A curve passing through the points thus found will give the shape of that section in the body plan. A better way is to take off the *heights* and *breadths* of *each section* separately, commencing with the *midship section*, which is often drawn on both sides; the sections of the *fore body* being drawn on the *right*, and those of the *after body* on the *left*-hand side of the *middle line*. The sections of the body plan will end at the half-siding of the keel, stem or stern-post as to breadth, and at the lower edge of the rabbet of the keel as to depth in each section.

When the intermediate water-lines are *parallel* to the *base*, the breadths have merely to be set off on them. In drawing these sections of the body plan, the irregular curves must be used and each line drawn in small pieces. After a little practice this is very easy, although at first some difficulty may be experienced in forming fair and correct curves. By tracing about a dozen body plans the student will become accustomed to the use of the curves. When the body plan is so far completed it may be necessary to "*fair the body*" by running *diagonal* and *buttock* lines. In transferring the former from the body to the half-breadth plan, the distance of each section is taken on the line of the diagonal from the middle line of the body plan, and applied to the corresponding section of the half-breadth plan. A batten passed through these points will detect any unfairness in the line, which must be corrected. A *diagonal* line ends in the half-breadth plan at the height of its intersection with the half-siding of the stem or stern-post in the body plan, transferred to the rabbet in the sheer plan, and squared down to the half-breadth; on this the diagonal distance of the middle line to the half-siding line of the body plan is set off, which gives the ending required.

A *buttock*-line in the body and half-breadth plans is drawn parallel to the middle line, the distances of its intersection with each section from the base are transferred from the body to the sheer plan, and a batten passing through these spots will detect any unfairness; or, as a further proof, the intersection of each water-line with the buttock-

line in the half-breadth plan may be squared up to the respective water-lines in the sheer plan; and if the buttock-line of the sheer plan does not agree with these last-found points, some alteration must be made until the body is fair, which is the case when all the intersecting points exactly coincide, and the diagonal, buttock and water-lines of each plan are fair lines. The forward portion of the *buttock*-line is called the *bow* line.

In the foregoing description the body and half-breadth plans are drawn to the outside of the *plank;* in the ship-builder's working drawings the outside of the *timbers* only is shown. In this case the sections of the body plan and the water-lines of the half-breadth plan are ended by describing an arc of a circle with the radius of the thickness of the plank from the ending before found as a centre; the lines will end at the back of this arc.

The best rule in copying a drawing is to take as few points as possible from the original, and to find the points in one plan *from those in another;* by this means any error is much less likely to produce an unfair or impracticable drawing.

The *model* is a feature peculiar to American ship-building. Models were made in Europe as early as the middle of the last century; but they were what would be recognized as the skeleton model, made of pieces representing the half frames, and were neither adapted to the purposes of building nor of exhibiting the lines of flotation. The invention of water-line models was the result of accident. In the Eastern States and in the British provinces men who were unacquainted with the art of constructing upon paper, made, from a block, the form of the vessel they intended to build, which was cut in several transverse sections. These sections, representing *frames,* were then expanded from the scale upon which the model was made to the size of the vessel; and frames were worked out to which *harpens* were attached, and the intermediate spaces filled in by making *moulds* to these harpens. In making one of these block models, the block was found to be too small to give the required depth; a piece was therefore added, and when finished it was discovered that the longitudinal form of the vessel was shown by the line uniting the two pieces together. The question at once arose, if one seam was an advantage, would not two be a still greater. Hence, as early as 1790, *water-line models* were made for building purposes.

There is still preserved in the rooms of the East India Marine Society, at Salem, Mass., the model of a "ketch" called the Eliza, 190 tons burden, which was launched in June, 1794. This model was made in three pieces on the scale of one-quarter of an inch to the foot—eighty-four feet keel, twenty-four feet beam and nine feet hold. The model has been preserved on account of the remarkable sailing qualities the vessel possessed. The Eliza and the celebrated frigate Essex were both built at Salem by the same constructor.

The Ohio 74, was built from a model under the supervision of Mr. Henry Eckford, at the Brooklyn Yard in 1820, and since that time the model has been considered in this country an indispensable feature in the designing of a ship.

In giving the method of constructing models, it will be here assumed that the *eye* is the only guide in giving the form, having decided upon the particular kind of vessel wanted.* The dimensions of the ship and the altitude of the load-line of flotation above the base-line being known, the portion between these lines may be divided into equal or unequal parts as occasion may require. If the ordinary mode is adopted, of making the alternate sections of *cedar* and *pine*, the lowest piece should be of cedar, because it presents to the action of the file the largest surface, and is more easily made fair than pine. If the ship is to have but little *dead rise*, the lowest piece should be the thinnest, on account of having a line at the lower part of the *bilge* which facilitates the laying off on the floor of the mould-loft. In determining the altitudes of the load-line of flotation, it does not arbitrarily follow that the model shall have no parallel pieces above this line, the effect of which is to reduce the thickness of the first *sheer-piece*. The proportions of depth of ships are calculated from the base-line or top of the keel to the lower side of the *plank sheer*, or, as it is sometimes called, *covering board;* and, as a consequence, one sheer line should be shown on the model at this height, measured on the *greatest transverse section*. The whole number of pieces may be confined with *dowels* running perpendicularly to the surface, or they may be screwed together in layers. As the model represents but *half* the ship, as a consequence, one side must present a plane which must be perfectly fair; and upon this plane

* Many builders make a rough drawing first and construct a model from it; this is much better than forming the model by the eye.

the sheer plan is projected in lead-pencil. This plan, which is the first laid off, whether on the model or on the floor, is bounded by the base-line, the rabbet on the stem and that of the stern-post, and the upper sheer, which is regarded as the lower side of the rail; hence it follows that the sheer plan determines the length of the ship, and the heights at the several sheers and water-lines, or parallels to the line of flotation. The materials for the model having been arranged and secured, either with screws or dowels, and the plane, representing the middle line, made perfectly fair, we may dress the opposite side parallel to the first, setting off, at certain intervals, the half-breadths of the intended ship. With regard to the shape of the greatest transverse section, from 4 to 6 degrees of rise for steamers, and as much as 8 degrees for sailing vessels, gives an easy bilge, and, while it ensures stability, prevents rolling. With regard to location, it would seem most important that the bow should be adapted to divide the water with the least possible resistance; though experience has proved that it is quite as essential to facilitate the escape of the displaced water along the side of the vessel; for when once a passage is opened for the ship, the fluid tends to reunite abaft the point of greatest breadth, where, instead of offering resistance, it presses the ship forward, in its endeavor to recover its level and fill the vacuum constantly opening behind her. After settling upon the greatest transverse section as judgment may dictate, the model is worked off until it suits the eye and taste of the architect.

Many useful discoveries may be made by models; and from experiments with them, *carefully conducted*, results may be obtained with as much certainty as by ordinary calculations; at all events, they may serve as a check upon them.

CHAPTER XXVI.

CONSTRUCTION.

HAVING now given some general idea of the mode of making a ship-drawing and constructing models, the student of naval architecture may proceed to the construction of a small vessel (say a yacht) on the simplest or *tentative* method, in which the amateur constructor takes as his guide an existing vessel or vessels of known good qualities, most nearly resembling that which he proposes to construct, and proceeds to adopt that which is good in the vessel he has chosen as his model, and to improve upon that which is bad. The following points require very careful consideration: 1st. Displacement. 2d. Length. 3d. Breadth. 4th. Depth at side and draft. 5th. Drag. 6th. Rake of stem and stern-post. 7th. Height of deck above the load water-line, amount of sheer and height of the bulwarks. 8th. Position of the midship or ⊗ section. 9th. Form and area of the midship section. 10th. Load water-line, its ratio to displacement, midship section and circumscribing parallelogram. 11th. Centre of buoyancy, or centre of gravity of displacement. 12th. Inclined water-line. 13th. Stability. 14th. Size of rudder. 15th. Area and centre of effort of sails, and position of the latter in regard to the centre of lateral resistance. 16th. Angle of sail. 17th. Size of masts and spars, rake of masts, etc.

There are several methods of construction in common use at the present day. Probably the most scientific system of all is Scott Russell's "*wave* system," of which an account has already been given. There is also the ordinary system in vogue in this country, the "parabolic system;" and finally, somewhat similar to this, a method of construction by means of a curve of vertical sections.

The common method of designing a vessel is that which discards

all mechanical rules for forming the various lines, and relies entirely on a consideration of those forms which experience has taught are best adapted to the particular object in view.

To enable a constructor to design a vessel by this method, it is essentially necessary that he be provided with drawings, models and calculations of vessels of similar size already built; from these he can adapt and modify such parts as he considers are applicable to his purpose. When the rough drawing is made, the displacement, areas of midship section and load water-line, and the position of the centre of gravity of displacement, must be calculated; should the results differ materially from those of the precedents, the constructor must consider the probable effect of such difference upon his intended vessel, and then make such alterations in the design as he imagines necessary, repeating the calculations and making further alterations if requisite, until the result accords with his intention; and unless anything *very novel* or extraordinary is attempted, this method will succeed pretty well, though of course much will depend upon the proficiency of the constructor and the extent and quality of his precedents. Without these the system is obviously insufficient.

The parabolic system of naval construction was discovered by the celebrated Swedish admiral, Chapman, and its applicability, completeness and *simplicity* render it well adapted for every description of vessel.*

By it the naval architect can determine every particular of his vessel; he can be certain that she will have the required displacement, possess the proper amount of stability and trim as he intends: he has nothing to do but, after making a few preliminary calculations, to proceed to trace the vertical sections of the body plan. Nor do the advantages of the system stop here, as every variety of form, both of water-line and vertical section, is equally applicable; in fact, the architect has great latitude in the shape of his vessel, so long as he does not depart from the areas and centres of gravity *settled upon at the outset.* The outline of this method of construction is simply this.

Chapman endeavored to discover how far the areas of consecutive sections of the best-known vessels followed any regular law. He therefore divided the area of each section by a constant quantity, *the*

* There is also a parabolic system known as "Nystrom's," which is somewhat similar to Chapman's.

breadth of the midship section, and set off distances proportional to these quotients on perpendiculars to a base line, the perpendiculars being placed at intervals equal to the distance between the sections, and he found that the curve which passed through the ends of these perpendiculars might be conveniently represented as a *parabolic curve,* both in the fore and after bodies, the *vertex* of the curve being at the *middle* of the *base line,* and the line representing the *midship section* forming the *axis.*

In ships the exponent of this curve is generally found to vary from 1.8 to 2.8, according to the fineness of the ship's ends in proportion to the midship or ⊗ section, and is generally found to be greater in large ships than in small ones. By the parabolic system it is easy to make up a drawing for a ship exactly to a predetermined displacement, and in such a manner that the *centre of gravity of displacement* shall come exactly in the place, according to the ship's length, that is deemed most favorable for good steering, manœuvring and stowage, which is of great consequence.

Although the exponent of the curve of sections varies considerably in different ships, it may for all sailing merchantmen be taken to be 2.5; and only when a ship is to be very large can a greater exponent—as, for instance, 2.6—be recommended. If the principal point is to obtain more than ordinary good sailing qualities, the exponent of the line of sections ought to be taken less than 2.5, say from 2 to 2.3. For men-of-war and merchant steamers it may be laid down as a general rule that the exponent of the line of sections is to be from 2 to 2.3, so that, for a displacement of 5000 cubic feet or less, the exponent may be 2 or 2.1; for a displacement of from 5000 to 10,000 cubic feet, 2.1 to 2.2; and for a displacement greater than 10,000 cubic feet, the exponent of the line of sections may be 2.2 or 2.3. For yachts and racing vessels the exponent may be as little as 1.3, but this is rather unusual. The exponent of the line of sections in the yacht "America," one of the most beautiful models ever constructed, is 1.339.

In order, then, to construct a yacht by the parabolic system, the amateur naval architect must begin by assuming Chapman's fundamental equations—

$$n = \frac{D}{l\,M - D} \qquad (1)$$

$$k = (n + 2) \times a \qquad (2)$$

$$y^n = p\,x \qquad (3)$$

Where D is the load displacement in cubic feet,

l is the length of the load water-line in feet.

a is the distance of the centre of gravity of displacement from the middle of the water-line in feet.

k is the distance of the midship section from the middle of the water-line in feet.

n being what is termed the exponent of the parabolic curve.

p the parameter.

The two last quantities being used to assist the calculations; n is determined from equation (1), and p from the formula—

$$p = \frac{\left(\frac{l}{2} \pm k\right)}{M} \qquad (4)$$

which is, in fact, a particular form of 3, and where, when the centre of gravity of displacement is abaft the middle of the water-line, the plus sign is used for the fore body, the minus sign for the after body, and *vice versâ* when the centre of gravity of displacement is before the middle.

x and y being co-ordinates of the curves; or, in other words, y is the distance of any one section from the midship section, and x the difference between a line representing the area of the midship section and a line representing the area of any other section.

From this last definition it follows that

Area of section $= M - x$

and from 3 $\quad x = \frac{y^n}{p} \qquad (5)$

The designer has now the means of ascertaining the areas of the successive sections by calculating n and p, and then substituting the successive values of y in the equation (5).

In practice the calculations are confined to one-half the vessel only, and therefore, instead of x and M, one-half of these values is taken; and with some degree of inaccuracy in the tables, as usually constructed, these halves are treated as whole areas.

For the sake of illustration, suppose the amateur about to design a schooner yacht, where the

		Feet.
Load displacement	$= D =$	5040
Length of load water-line	$= l =$	80
Area of midship section	$= M =$	110

Distance of the centre of gravity of displacement from the middle $= a = 1.6$ feet abaft.

First, find n which $= \dfrac{D}{l\,M - D}$ (1)

Or $= \dfrac{5040}{80 \times 110 - 5040} = 1.34$

Next, $k = (n + 2) \times a$ (2)

Or $= (1.34 + 2)\ 1.6 = 5.34$ abaft.

Then for the fore body,

$$\log.\ 2\,p = \log.\ 2\,\frac{\left(\frac{l}{2} + k\right)^n}{M} = \log.\ \frac{\left(\frac{80}{2} + 5.34\right)^{1.34}}{55} = 478165 = \log.\ 3.$$

For the after body,

$$\log.\ 2\,p = \log.\ 2\,\frac{\left(\frac{l}{2} - k\right)^n}{M} = \log.\ \frac{\left(\frac{80}{2} - 5.34\right)^{1.34}}{55} = 3245167 = \log.\ 2.11.$$

As this quantity is used in multiplication simply, the logarithm of it only need be found; then, by substituting the successive values of y in the equation

$$x = \frac{y^n}{p}$$

and calculating the successive values of x by logarithms, the following table is constructed:

14

TABLE XXVII.

For the fore body	$\frac{x}{2} = \frac{y^{1.34}}{3}$	
y or distance from the midship section.	$\frac{x}{2}$ or abscissa.	Half area of midship section $-\frac{x}{2} =$ half area of section.
feet.	sq. feet.	sq. feet.
7.5	4.95	50.05
15.0	12.5	42.5
22.5	21.5	33.5
30.0	31.7	23.3
37.5	42.8	12.2
For the after body	$\frac{x}{2} = \frac{y^{1.34}}{2.11}$	
y or distance from the midship section.	$\frac{x}{2}$ or abscissa.	Half area of midship section $-\frac{x}{2} =$ half area of section.
feet.	sq. feet.	sq. feet.
7.5	7.05	47.95
15.0	17.9	37.1
22.5	30.7	24.3
30.0	45.2	9.8

A little careful study of the foregoing will enable any one with a slight knowledge of logarithms to comprehend the working of the system. No more calculations are required, as the position of the centre of buoyancy, the displacement and the area of the midship section are all, by Chapman's method, *predetermined* quantities, and form the basis of the design; therefore to calculate them after the design is completed would be merely a useless repetition.*

Before proceeding with the construction drawing of the schooner yacht taken as an example, it will be well to give the principal pro-

* Dr. Wooley, Vice-President of the Institution of Naval Architecture in England, calls Chapman's system a "*quasi scientific*" one, on the ground that it tends to stereotype particular models and thus check improvement. This, however, is the only objection alleged against it. It undoubtedly does away with the necessity of the laborious and scientific calculations required by Scott Russell's "wave system."

portions which experience has shown to be useful and applicable to such vessels:

The breadth generally = the length × .26 for fast schooners.

The depth generally = the breadth × .3952.

The area of midship section = breadth × depth × .6.

The area of load water-line = breadth × length × .7021.

Load displacement in cubic feet = length × breadth × depth × .3623.

The midship section from the fore end of the water-line = length × .517.

The centre of gravity of displacement from the fore end of the water-line = length ×. 55 for schooners.

Or generally = length × .02 abaft the middle.

In making the construction drawing, the same order is to be observed as in copying, but the draughtsman is left to his own resources as to the dimensions and forms of the different parts. His first care should be to understand distinctly and exactly the sort of vessel required. Let it be assumed, then, that this schooner yacht is to be 144 tons, or 5040 cubic feet the displacement required—the draft of water not to exceed eleven feet, and that she is to have as much speed as is consistent with a certain degree of accommodation. In Fincham or Marrett the student will find tables giving the dimensions of some vessel of suitable character and *similar displacement*, and is thus enabled to fix the length of the water-line at 80 feet, then the breadth $= .26\,l = 20.8$ feet.

But in this case, as the breadth is rather limited and accommodation is a desideratum, it may probably be better to give a small additional breadth to ensure sufficient stability, displacement and accommodation. Suppose, therefore, the breadth is determined at $.27\,l = 21.5$ feet, then the depth $= .3952\,b = 8.5$ feet.

If to this is added one foot for the depth of the keel below its rabbet, the mean draft of water is made 9.5 feet, and with the maximum draft of eleven feet aft, this gives eight feet for the draft of water forward. This, however, is rather more "drag" than may be advisable, and therefore the draft forward may be increased to nine feet with advantage.

The load displacement = length × breadth × depth × .3623 =

5.296 cubic feet = 151 tons, an excess of seven tons above that required, or

$$\frac{\text{displacement}}{\text{length} \times \text{breadth} \times \text{depth}} = \frac{5040}{14620} = .3447$$

or the proportion the displacement (5040 cubic feet) bears to the circumscribing parallelopipedon.

The constructor will judge by comparison whether this proportion is adapted to the required purpose; if not, some alteration in the dimensions must be made.

The area of the midship section = breadth $\times$ depth $\times$ .6 = 110 square feet.

The exponent of the parabolic curve,

$$n = \frac{\text{D}}{l\text{M} - \text{D}} = \frac{5040}{80 \times 110 - 5040} = 1.34.$$

Which nearly corresponds with the value of n in the case of the yacht "America," and therefore it may be presumed that the proposed vessel will, by assigning that value to n, be of proportionate fullness in relation to the dimensions.

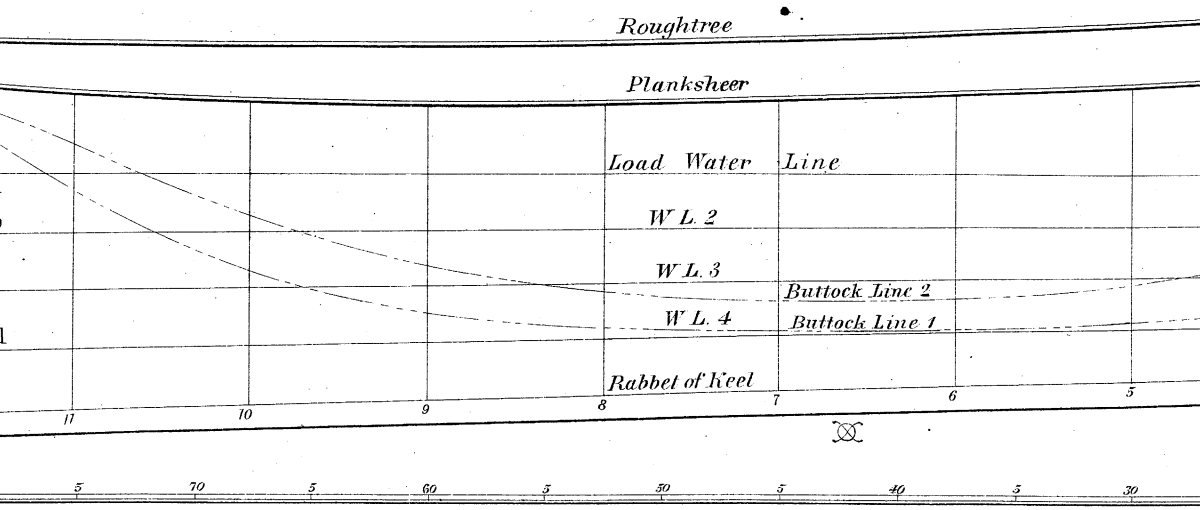
The distance of the centre of gravity of displacement abaft the middle of the load water-line will be length $\times$ .02 l = 1.6 feet = a, and the midship section will be from (2) 1.6 (1.34 + 2) = 5.34 feet *abaft* the middle.

The calculations for the areas of the sections of this vessel have already been given (page 210), and therefore no repetition is here necessary.

Having arranged these preliminaries, the drawing may be commenced: the sheer, rake of the stern and form of the counter can be taken from tables or from other drawings, and altered to suit the constructor's judgment. The midship section in the sheer plan must be drawn at its proper distance from the fore end of the load water-line, and the other sections at the determined distances from the midship section; in the present case they are placed at intervals of seven feet six inches. In designing the midship section, which is done in the body plan, care must be taken that the half area should equal 55 square feet exactly; the section being sketched in by the eye. Its area may, in this preliminary part of the work, be found by the "short rule," page 221, thus:

Fig. 27

SHEER PLAN



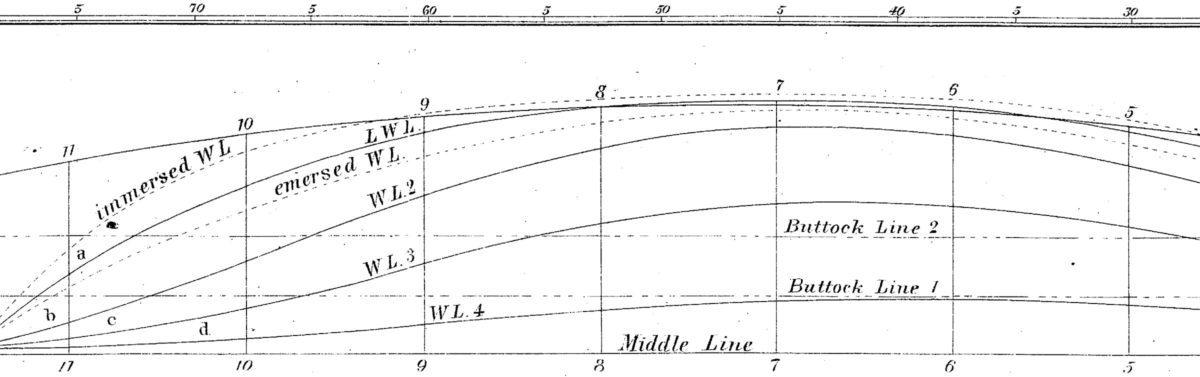


Fig. 28

HALF BREADTH PLAN

	Ordinates.	
Load water-line,	10.75	(half)
Second water-line,	10.1	
Third water-line,	7.0	
Fourth water-line,	2.4	
Keel,	.3	(half)
	25.025	
	2.2	= distance between water-lines.
	55.055	

It is hardly to be expected that, at the first trial, the midship section will be drawn of the correct area, but after one or two alterations it will generally be obtained. When this is done, the load water-line from the midship section to the fore end must be drawn in the half-breadth plan. Having determined from Fincham or Marrett's tables of construction, or from other sources, the angle which it should make with the middle line forward, a line can be drawn for some distance from the ending at that angle; then, with a small penning batten, the breadth at the midship section is joined to this line; this will give a "straight" water-line. When any hollow is required in the water-line, the batten may be continued to the ending, describing the hollow required, or the load water-line may be formed according to the "*wave*" system, if the constructor prefers that system.

The half-breadth lines of the deck and *roughtree rail* may next be drawn of such shape as the constructor thinks best. A section intermediate with the midship section and foremost extremity drawn in the body plan (the half-breadth at the load water-line being taken from the half-breadth plan), and altered, if necessary, until its half area corresponds with the area already determined for such section, will be a guide for drawing the other water-lines of the *fore body* in the half-breadth plan. When the remaining sections are drawn, if their areas do not agree with the calculated areas, alterations must be made.

The *after-body* is proceeded with in a similar manner, and when the whole of the sections are completed, the designer may, perhaps, require some alterations to be made.

When such alterations from the original plan involve any con-

siderable change of form or alteration of the several sectional areas, it may be advisable to calculate the displacement and the position of the centre of gravity of displacement, etc., in order to prevent too great a deviation from the original intention; but when no alteration, or at least only a slight one, is made, this is not necessary. Figs. 26, 27 and 28 show a design for a schooner yacht in conformity with the foregoing dimensions and calculations, and without any material alterations from the established areas, in order to show how well adapted for construction the parabolic system is.

To complete the vessel, the masts and sails have to be arranged. The area of the vertical longitudinal section $= l \times h = 80 \times 10 = 800$, and the area of load water-line $= l \times b \times .7 = 1204$, these sums multiplied together $= 963200$, which is the co-efficient for the dimensions of the spars. (Table XXVIII.)

The centre of effort should be placed at .006 of the length of load water-line $= .48$ feet abaft the centre of gravity of vertical longitudinal section, and at the height of the centre of effort, the main-mast will be one-tenth of the length of the water line $= 8$ feet abaft the centre of the vertical longitudinal section. The foremast will be .344 of the length of the water-line $= 27.5$ feet before the mainmast.

With these positions, a sail drawing as in fig. 29 must be made to the dimensions given in Table XXVIII., and the area of sail and position of centre of effort both as to height and length calculated. If the results do not agree with the established position for the centre of effort, some change must be made, either by readjusting the proportion of fore-and-after sail, or by moving the masts and preserving the same measurement of spars, as it is imperatively necessary that a proper and correct balance of sail should exist; otherwise, the care of the constructor in designing the hull has been completely thrown away.

If the vessel is constructed on the "*wave*" theory, the mode of balancing the sail has already been shown.

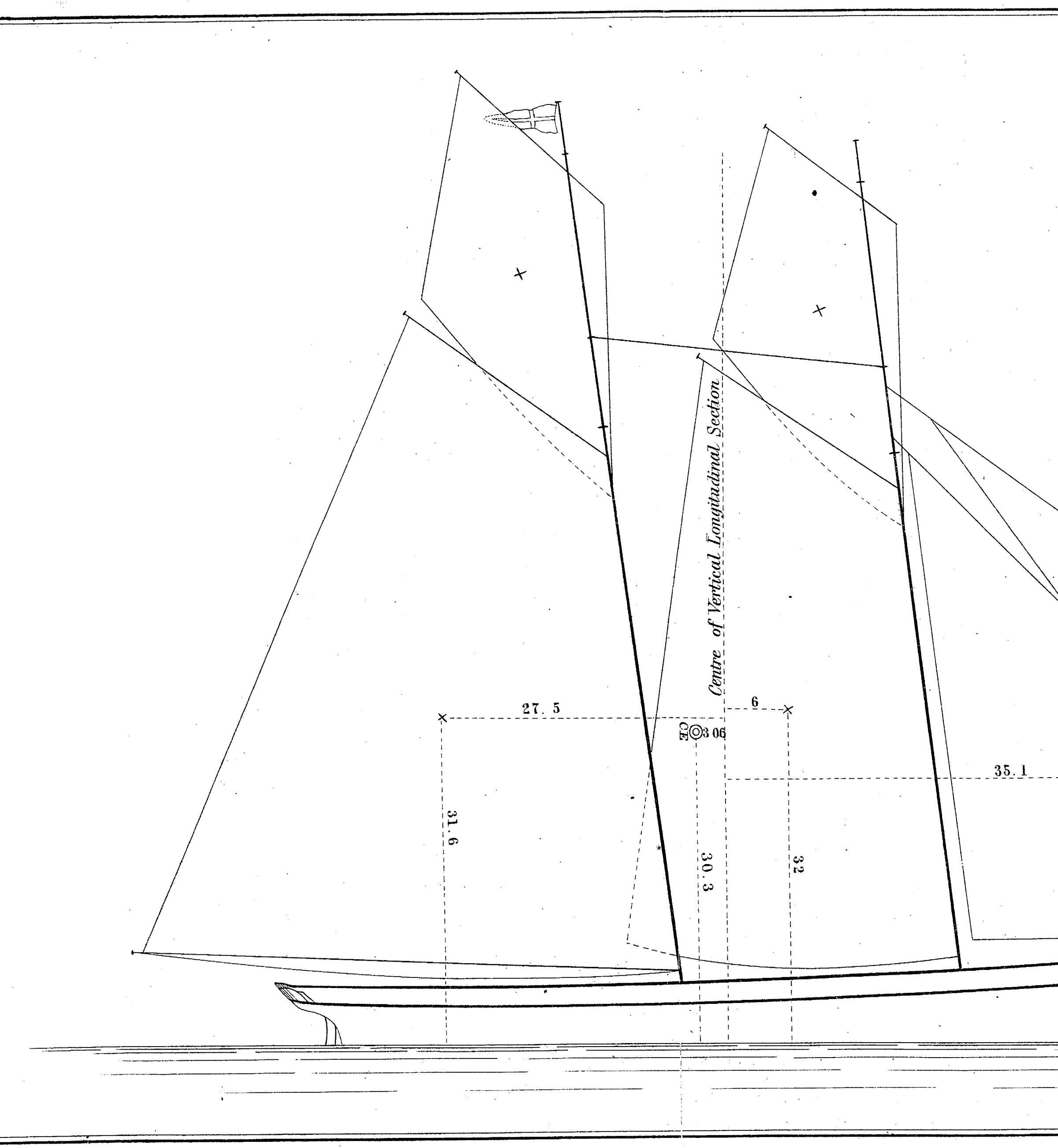

Centre of Vertical Longitudinal Section
27. 5
6
CE
3 06
35. 1
31.6
30. 3
32

TABLE XXVIII.

Proportions and Dimensions of Spars for Fast Schooners.

Unit W × area V. L. S.	Moment of Sails.	Height of C. E.	Area of Sails.	Hounded length of Mainmast.	Mast Head.	Hounded length of Foremast.	Mast Head.	Main Topmast to hounds.	Main boom.	Main gaff.	Fore gaff.
500000	75370	23.9	3153	53.6	6.9	50.6	6.6	21.4	42.8	19.2	18.7
520000	77682	24.15	3216	54.2	6.9	51.2	6.7	21.7	43.4	19.5	18.9
540000	79994	24.4	3278	54.8	7.0	51.7	6.8	21.9	43.8	19.7	19.2
560000	82306	24.65	3340	55.4	7.1	52.3	6.9	22.1	44.2	19.9	19.5
580000	84618	24.9	3398	56.0	7.2	52.9	7.0	22.4	44.8	20.1	19.7
600000	86930	25.2	3450	56.6	7.2	53.4	7.0	22.6	45.2	20.3	19.9
620000	89242	25.45	3506	57.2	7.3	54.0	7.1	22.8	45.6	20.5	20.1
640000	91554	25.7	3562	57.8	7.4	54.5	7.2	23.1	46.2	20.7	20.3
660000	93866	26.	3610	58.4	7.5	55.1	7.3	23.3	46.6	21.0	20.5
680000	96178	26.2	3670	59.0	7.5	55.6	7.3	23.6	47.2	21.2	20.7
700000	98490	26.5	3716	59.6	7.6	56.2	7.4	23.8	47.6	21.4	21.0
720000	100802	26.75	3768	60.2	7.7	56.8	7.5	24.0	48.0	21.6	21.2
740000	103114	27.	3820	60.8	7.8	57.4	7.5	24.3	48.6	21.8	21.4
760000	105426	27.3	3860	61.4	7.8	58.0	7.6	24.5	49.0	22.0	21.6
780000	107738	27.55	3910	62.0	7.9	58.6	7.7	24.8	49.6	22.2	21.8
800000	110050	27.8	3958	62.6	8.0	59.2	7.8	25.0	50.0	22.5	22.0
820000	112362	28.05	4006	63.2	8.1	59.8	7.9	25.2	50.4	22.7	22.2
840000	114674	28.35	4045	63.8	8.1	60.3	7.9	25.5	51.0	22.9	22.5
860000	116986	28.6	4098	64.4	8.2	60.9	8.0	25.7	51.4	23.1	22.7
880000	119298	28.85	4135	65.0	8.3	61.4	8.1	26.0	52.0	23.3	22.9
900000	121610	29.1	4179	65.6	8.4	62.0	8.2	26.2	52.4	23.5	23.1
920000	123923	29.4	4215	66.2	8.4	62.5	8.3	26.5	53.0	23.7	23.3
940000	126234	29.65	4257	66.8	8.5	63.1	8.4	26.7	53.4	24.0	23.5
960000	128548	29.9	4300	67.4	8.6	63.6	8.4	27.0	54.0	24.2	23.7
980000	130858	30.15	4340	68.0	8.7	64.1	8.5	27.2	54.4	24.4	24.0
1000000	133170	30.4	4377	68.6	8.7	64.7	8.6	27.4	54.8	24.6	24.2
1020000	135482	30.65	4420	69.2	8.8	65.2	8.7	27.6	55.2	24.8	24.4
1040000	137794	30.95	4452	69.8	8.9	65.8	8.7	27.9	55.8	25.0	24.6
1060000	140106	31.2	4490	70.4	9.0	66.3	8.7	28.1	56.2	25.2	24.8
1080000	142418	31.45	4528	71.0	9.0	66.9	8.8	28.3	56.6	25.5	25.0
1100000	144730	31.7	4565	71.6	9.1	67.4	8.9	28.6	57.2	25.7	25.2
1120000	147042	32.	4595	72.2	9.2	68.0	9.0	28.8	57.7	25.9	25.4
1140000	149354	32.25	4630	72.8	9.3	68.5	9.1	29.1	58.2	26.1	25.6
1160000	151666	32.5	4666	73.4	9.3	69.1	9.2	29.3	58.7	26.3	25.8
1180000	153978	32.75	4700	74.0	9.4	69.7	9.3	29.6	59.2	26.5	26.0
1200000	156290	33.	4736	74.6	9.5	70.2	9.3	29.8	59.7	26.7	26.2
1220000	158602	33.3	4762	75.2	9.6	70.8	9.4	30.1	60.1	26.9	26.4
1240000	160914	33.55	4796	75.8	9.6	71.3	9.4	30.3	60.6	27.2	26.6
1260000	163226	33.8	4830	76.4	9.7	71.9	9.5	30.5	61.1	27.4	26.8
1280000	165538	34.05	4860	77.0	9.8	72.4	9.6	30.8	61.6	27.6	27.0
1300000	167850	34.3	4893	77.6	9.9	73.0	9.7	31.0	62.2	27.8	27.2
1320000	170162	34.55	4925	78.2	9.9	73.6	9.7	31.3	62.6	28.0	27.4
1340000	172474	34.8	4956	78.8	10.0	74.2	9.8	31.5	63.0	28.2	27.6
1360000	174786	35.1	4980	79.4	10.1	74.7	9.9	31.7	63.5	28.4	27.8
1380000	177098	35.35	5000	80.0	10.2	75.3	9.9	32.0	64.0	28.7	28.0
1400000	179410	35.6	5040	80.6	10.3	75.8	10.0	32.2	64.5	28.9	28.2
1420000	181722	35.85	5070	81.2	10.3	75.4	10.1	32.5	64.9	29.2	28.4
1440000	184034	36.15	5090	81.8	10.4	76.9	10.2	32.7	65.5	29.4	28.6
1460000	186346	34.4	5120	82.4	10.5	77.5	10.2	32.9	65.9	29.6	28.8
1480000	188658	36.7	5140	83.0	10.6	78.0	10.3	33.2	66.4	29.8	29.0
1500000	190970	37.	5160	83.6	10.6	78.6	10.4	33.4	66.5	30.0	29.2

Bowsprit end from foremast.	Jibboom beyond bowsprit.	Length.
35.5	17.8	67
36.0	18.0	68
36.5	18.3	69
37.1	18.6	70
37.6	18.8	71
38.2	19.1	72
38.7	19.4	73
39.2	19.6	74
39.7	19.9	75
40.2	20.1	76
40.8	20.4	77
41.3	20.6	78
41.8	20.9	79
42.4	21.2	80
42.9	21.5	81
43.4	21.7	82
44.0	22.0	83
44.5	22.3	84
45.0	22.5	85
45.5	22.8	86
46.1	23.1	87
46.6	23.3	88
47.1	23.6	89
47.7	23.8	90
48.2	24.1	91
48.8	24.4	92
49.3	24.6	93
49.8	24.5	94
50.4	25.0	95
50.5	25.2	96

CHAPTER XXVII.

CURVE OF SECTIONAL AREAS APPLIED TO NAVAL CONSTRUCTION.

In order to determine the displacement, say of a man-of-war, by this method, the naval architect must, as previously shown, take into consideration the armament and its weight, the number of men necessary to work and fight the ship, the weight of boilers, engines and fuel, the weight of provisions and stores of all kinds for the particular service on which it is intended to employ the ship, and the weight of the hull and fastenings when completed.

The displacement fixed by these weights having been obtained, the relative lengths and displacements of the fore body and after body must next be determined, then the area of the midship or ⊗ section may be found by the following equation, the decimal part of it being varied to suit the views of the designer, or the peculiar service required of the vessel; as under a given displacement the "area of the immersed midship or ⊗ section" will regulate the fullness of the bow and quarters of the vessel.

The length on the load water-line from the fore part of the rabbet of the stem to the after part of the rabbet of the post, multiplied by the area of midship section, multiplied by the decimal fraction (determined upon) will equal the displacement.

As an example, the fraction 0.7 has been found to give the area of midship section well adapted to heavy frigates. So the equation will stand thus:

$$\text{Area of midship or ⊗ section} = \frac{\text{Displacement in cubic feet}}{\text{Length of load water-line} \times 0.7}.$$

This area having been determined, for convenience in delineating a curve of vertical sectional areas on paper, take a sub-multiple of

that area by dividing the *half area* of the midship section by a quantity that will give a quotient less than the half-breadth of the intended ship, and call this the "middle ordinate of the curve of sectional areas." (The draft of water is usually the quantity used as the divisor.)

The curve, when determined, will bound an area that to the depth assumed by the divisor will be a solid equivalent to the *half* solid of displacement. (See fig. 30.)

Next, set off the length of the load water-line from rabbet of stem to rabbet of post; divide that length into two equal parts, and at the middle point of the load water-line erect a perpendicular, making it equal in linear measurement (from a scale of parts) to the "middle ordinate of the curve of sections;" complete the triangles by joining the extremes of the load water-line and the end of this ordinate, and find the areas of these triangles, which are similar and equal by construction. The respective differences between the *intended* displacements in cubic feet of the fore and after bodies, and the areas of these triangles will give the required areas to be developed under the curves on the hypothenuse of each triangle. When these curves are delineated, so that the area included between the whole curve and the load water-line makes up a sub-multiple of the half displacement, then ordinates measured perpendicularly from any point of the load water-line to the curve will be sub-multiples of the area of the transverse section of the immersed body at that point. It will be seen that in this case the quantities given are—

1st. Whole displacement;

2d. Relative displacements of the fore and after bodies and percentage on the whole displacement;

3d. Length on load water-line and length of entrance;

4th. Breadth;

5th. Draft of water;

6th. Decimal or co-efficient of fineness;

in order to find the areas of the different cross sections, and consequently the shape of the water-lines.

Construction by Curve of Sectional Areas Applied to a Particular Example.

Sailing ship of 2300 tons moulded displacement.

Given—

Displacement = D = 2300 tons = 80,500 cubic feet of 35 to the ton, and half displacement = 40,250.

Length on the load water-line assumed = 172 feet.

Breadth " " " = 46 "

Then the area of midship section

$$= \frac{\text{Displacement}}{\text{Length of load water-line} \times .7} = \frac{80{,}500}{172 \times .7} = 668 \text{ feet.}$$

Assuming the relative capacities of the fore and after bodies as 4 per cent. on the whole moulded displacement, will give, on the 2300 tons, 92 tons.

The half displacement	= 1,150 tons	
The half difference of the capacities............	= 46 "	
Sum	1,196	= capacity of fore body.
Difference..............	1,104	= capacity of after body.
Whence................	598	= ½ fore body = DFCB. } Fig. 30.
	552	= ½ after body = DHAB. } Fig. 30.

Or 20,930 cubic feet for ½ fore body, each ton being considered equivalent to 35 cubic feet.

19,320 cubic feet for ½ after body.

Half area of midship section....... = 334 feet.

Half-breadth .... = 23 "

Dividing the half area of midship section by 30, gives 11.1 feet for the "middle ordinate of the curve of sections," and 30 becomes the multiple for the representative areas of the solid.

The length of the load water-line divided by 2 = 86 ft. = AB or BC.

The representative area

$$\text{ABD or CBD} = \frac{\text{BC} \times \text{BD}}{2} = \frac{86 \times 11.1}{2} \text{ or } 477.3 \text{ feet,}$$

which, multiplied by 30, gives 14,319 feet for the displacement of the triangular portion of the solid in fig. 30.

Now the displacement of half fore body.... = 20.930 cubic feet.
And the area of triangle DBC................ = 14.319 " "
Hence the difference equals the representative area bounded by the curve DECF... = 6,611 " "

The length of the hypothenuse DC by calculation, = 87.8 feet.
To find EF, substitute these values in the equation—

$$\frac{4}{3}\text{ EF} \times \text{DC} = \frac{\text{D}}{2} + \frac{2\text{D}}{100} - 2 \text{ (area of triangle ABD or CBD), or}$$

$$\frac{4}{3}\text{ EF} \times 87.8 \times 30 = \left(\frac{\text{D}}{2} + \frac{2\text{D}}{100}\right) - 2 \text{ (area of triangle ABD), or}$$

$$4 \text{ EF} \times 87.8 \times 10 = 40{,}250 + 1{,}610 - 28.638, \text{ and}$$

$$\text{EF} \times 3{,}512 = 12{,}889$$

Hence $\text{EF} = 3.76$ feet.

To find the value of GH, we have $\frac{2}{3}$ of EF $\times$ DC $-$ $\frac{2}{3}$ GH $\times$ AD $= \frac{2\text{D}}{100} = \frac{2}{3}\, 3.76 \times 87.8 \times 30 - \frac{2}{3}\text{ GH} \times 87.8 \times 30 = 1{,}610$

or $2 \times 3.76 \times 87.8 \times 10 - 2\text{ GH} \times 87.8 \times 10 = 1{,}610$; hence

$$6602.56 - 1{,}610 = 1{,}756 \times \text{GH, or GH} = \frac{4992.56}{1756} = 2.84 \text{ feet.}$$

Or GH = 2.84 feet nearly. Also, DE = $\frac{2}{3}$ of DC = $\frac{2}{3}$ of 87.8 = 58.7 feet for the position of the abscissa, FE, from D on the line DC.

An examination into this simple method of construction will show its utility and capability; and though the method cannot be demonstrated to be strictly true in the mathematical sense of the term, yet it is sufficiently so for all practical purposes; and while it will never deceive, will very materially lighten the labors of the naval architect.

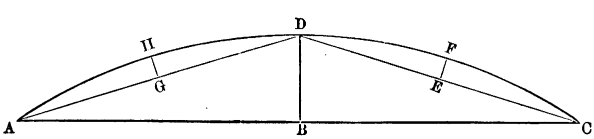


FIG. 30.

CHAPTER XXVIII.

MAKING THE CALCULATIONS.

THREE rules are in common use for measuring the area enclosed between a curve and a straight line taken as a base. The first is generally known as "Simpson's" rule or "Chapman's" rule; the second is called the "Three-eighths," or the "Three-plus-one" rule, and the third is known as the "Old" or "Short" rule.

Nearly all calculations in naval construction are made by these rules.

I. "Simpson's," or the first rule, is as follows: *Divide the base line, as* AC, *in fig.* 31, *into any* EVEN *number of equi-distant parts, and erect perpendicular* ORDINATES *at each point of division. The rule may then be expressed by the formula—*

Area $= (A + 4P + 2Q) \times \frac{r}{3}$

where A = the sum of the linear measurements of the first and last ordinates, as A1, C7;

4P = the sum of the *even* ordinates, as 2 2, 4 4, 6 6, multiplied by 4;

2Q = the sum of the remaining ordinates, as 3 3, 5 5, multiplied by 2;

and r is the linear measurement of the common interval between the

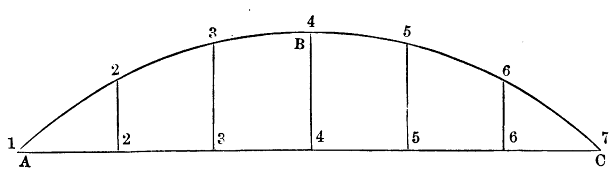


FIG. 31.

ordinates. All the above measurements to be taken from the same scale.

The formula may also be expressed as follows:

$$\text{Area} = \left(\frac{A}{2} + 2P + Q\right)\frac{2r}{3}$$

"Simpson's" rule is based on the supposition that the curve ABC is a portion of a *common parabola;* and therefore the nearer the ordinates are to each other the more correct will the area be.

II. The second or "*Three-eighths*" rule is as follows: *Divide the base line,* AC (*fig.* 32), *into any number of equal intervals which shall be in number a* MULTIPLE OF THREE. *At each point of division erect perpendicular ordinates as before. Then the area may be determined from the following formula:*

$$\text{Area} = (A + 2P + 3Q) \times \frac{3r}{8}$$

where A = the sum of the linear measurements of the first and last ordinates, as A1, C0;

2P = the sum of the linear measurements of the fourth, seventh, etc. (*three-plus-one*) ordinates multiplied by 2;

3Q = the sum of the linear measurements of the second, third, fifth, sixth, eighth, ninth, etc., ordinates multiplied by 3;

and r is the linear measurement of the common interval as before.

The formula may also be expressed as follows:

$$\text{Area} = \left(\frac{A}{2} + P + 1.5Q\right) \times \frac{3r}{4}$$

The "*Three-eighths*" rule supposes the curve ABC to be a portion of a *cubic parabola.*

III. The third or "*Short*" rule, sometimes called the "*Old*" rule, is as follows: *Divide the base line,* AC (*fig.* 33), *into a large number of*

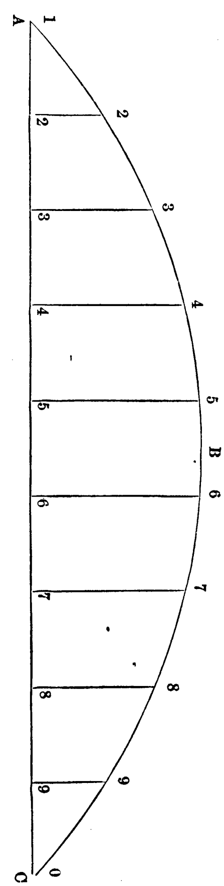


FIG. 32.

equal intervals, erect ordinates as before; then the area may be found by the following formula:

$$\text{Area} \qquad = \left(\frac{A}{2} + Q\right) \times r$$

where A = the sum of the linear measurements of the first and last ordinates, as A1, C5;

and Q = the sum of the linear measurements of the rest of the ordinates, 2 2, 3 3, 4 4;

and r is the common interval as before.

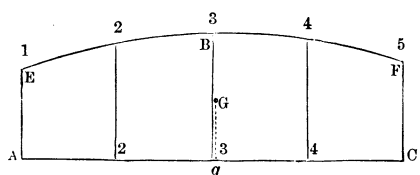


FIG. 33.

As a general rule in calculating areas or displacement when the *water-lines* or *sections* are very round, or when the *vertical sections* are more than *five* feet apart, either "Simpson's" rule or the "Three-eighths" rule should be employed; but when the lines are tolerably straight, and the *ordinates* are *less* than *five* feet apart, the "Short" rule will give a sufficiently accurate result, and from its greater simplicity is to be preferred; or two rules may be combined, as where the vertical sections are much curved, but the water-lines rather straight.

In order to find the displacement of a ship from the foregoing rules, the vessel is supposed to be divided by any number of equi-distant *horizontal* planes—that is, planes taken parallel to the load water-line—and also by any convenient number of equi-distant *vertical* planes, intersecting, of course, the former series of horizontal planes at right angles. These planes are *projected* by the draughtsman on the three plans of the vessel—viz., the *body* plan, the *sheer* plan and the *half-breadth* plan. (See figs. 26, 27 and 28.) As seen in the half-breadth plan (fig. 28), the vessel is divided into two equal portions by a vertical plane running from stem to stern; and the perpendicular distances measured on each horizontal plane, from their intersection with this plane to the vessel's side, are considered as ordinates.

Thus in the half-breadth plan (fig. 28), AB is the projection of the vertical plane which divides the vessel into two equal parts, and 1 1, 2 2, 3 3, etc., are ordinates in the horizontal plane. Any number of these horizontal planes may be taken, and for the purposes of calculation they may be numbered as water-lines 1, 2, 3, 4, 5, etc., or *a, b, c, d,* etc. (Figs. 27 and 28.) The small portions fore and aft are usually calculated separately, the horizontal and vertical planes being sometimes taken much nearer to each other in consequence of the greater curvature of the vessel at these parts.

The calculation of the displacement may then be proceeded with in *two* ways:

1st. By finding the *areas* of all the *horizontal* sections, and employing these as *ordinates* in Rule I. or II.

2d. By finding the *areas* of all the *vertical* sections, and using these as ordinates in the same rules.

These two results *ought* to agree.

Or the rule may be enunciated as follows, ordinates on the half-breadth plan being understood:

RULE IV. *To the sum of the* FIRST *and* LAST *horizontal sectional areas add* FOUR *times the sum of all the* EVEN *horizontal areas, and* TWICE *the sum of all the* ODD *horizontal areas; multiply this final sum by* ONE-THIRD *the common distance between these horizontal planes, and the result will be* ONE-HALF *the displacement.*

Observe that in the wording of the above rule, *vertical* areas may be employed in the place of *horizontal* areas, care being taken to omit the first and last areas from the *odd* ones in each case.

As the positions of the centres of gravity, both of the displacement and of the vessel are of much importance in the calculation of stability, the method of finding them will be given, premising that when bodies are *homogeneous,* or of the same density throughout their parts—that is, having equal weights comprised under equal volumes—*weights* may be replaced by *masses,* and conversely. Thus, if M represent the mass of a body, d the density of a unit of the body, V the volume, and W the weight, then

$$M = d \times V \qquad (1)$$
$$W = g \times d \times V = gM \qquad (2)$$

g is here the "accelerating force of gravity," is uniform and the

same for all substances, being, in the latitude of London, = 32.18 feet, according to Earnshaw's Dynamics.

To find the centre of buoyancy of a ship floating in the water and in a state of equilibrium.

RULE V. *Find the areas of all the horizontal sections (as shown in the half-breadth plan), and multiply these, beginning from the first or plane of flotation (load water-line) by the consecutive numbers* 0, 1, 2, 3, 4, *etc., respectively; introduce these products as ordinates into "Simpson's Rule;" multiply this result by one-third of the* SQUARE *of the common distance between the sections, divide by the volume, and the quotient gives the distance of the centre of buoyancy below the plane of flotation.**

RULE VI. *Find the areas of all the vertical sections, multiply these, beginning from the first,*† *by the consecutive numbers* 0, 1, 2, 3, 4, *etc., respectively, and work as in the last rule; the result thus obtained gives the distance of the centre of buoyancy from the first vertical plane.*

These two distances fix the position of the centre of buoyancy of the main body. No account is here taken of the small portions at the stem, stern and that between the keel and the last horizontal section. These are usually calculated separately and in the same way as the main body. Having obtained the centres of gravity (or buoyancy) of all these portions, we readily obtain the centre of gravity of the total displacement by the rule which follows: observing that if we consider the *first vertical plane* to be that nearest the bow, the volume of the small portion forward multiplied by the distance of its centre of gravity from the plane just mentioned must be *subtracted.* Or in other words, if we consider all horizontal distances, measured in the *opposite* direction (from the first vertical plane) to the centre of gravity of the main body as *negative,* and all distances measured in the *same direction* as *positive,* we have only to add the products *algebraically;* and this is to be understood in the following rule (one product being always *negative* in Rule VIII.). All *results will be positive* in finding the distance of the centre of buoyancy *below the plane of flotation.*

* Care must be taken *not* to multiply by one-third of the common distance, as is mentioned in Rule I.

† Either the first vertical section of the main body nearest the bow or stern may be taken as the first or initial plane.

To find the centre of buoyancy when the small portions, "fore and aft," are considered.

RULE VII. Multiply each of the volumes by the perpendicular distance of its centre of gravity from the plane of flotation, and add the products; divide this result by the sum of all the volumes, and the quotient is the distance of the centre of gravity of the total displacement below the plane of flotation. Also,

RULE VIII. Multiply each of the volumes by the perpendicular distance of its centre of gravity from the first vertical plane, and add algebraically (observing that one result will be negative); divide this result by the sum of all the volumes, and the quotient is the distance of the centre of gravity of the whole displacement (centre of buoyancy) from the first vertical plane.

In the foregoing rules, *half areas* and *half volumes* should be understood; as the calculations are applied to only one-half the ship.

To find the centre of gravity of an area similar to fig. 33.

RULE IX. *Multiply the ordinates, beginning at the first by* 0, 1, 2, 3, 4, *etc., respectively, and employ these as ordinates in Rule I.; multiply the result thus obtained by one-third of the common interval squared, divide by the area of the curve, and the result gives the distance we are to measure along* AC*;* as A*g* (fig. 33).

Having obtained the distance A*g*, we may obtain the length of the perpendicular, G*g* (G being the centre of gravity of the figure, and *g* the point where the perpendicular drawn from G intersects AC), by

RULE X. *To the sum of the* SQUARES *of the* FIRST *and* LAST *ordinates, add* FOUR *times the sum of the squares of all the* EVEN *ordinates, twice the sum of the squares of all the* ODD *ordinates; multiply by one-third the common interval, and divide this result by twice the area; the quotient gives the perpendicular height of the centre of gravity above the axis* AC.*

* The calculator will always have a check on his work by observing the length of the axis AC, and noting whether or not the ordinates near the beginning differ widely from those at the end. If the ordinates do not differ widely in this sense, the centre of gravity will be determined by a line perpendicular to the axis *near* its middle point. If the ordinates are greater near the beginning than at the end, the centre of gravity determined along AC will be nearer the *first* ordinate than the *last*, and *vice versâ*.

To determine the height of the meta-centre above the centre of gravity of displacement (centre of buoyancy), the following rule is made use of:

RULE XI. *Cube the ordinates measured on the half-breadth plan, introduce these* CUBES *as ordinates in Rule I., and proceed as therein stated; divide the result thus obtained by the volume of water displaced, and* TWO-THIRDS *of the quotient gives the distance of the meta-centre from the centre of buoyancy.*

To find the volume of the "shoulders:"

RULE XII. Measure the ordinates of the immersed water-lines, then to the *sum* of the *squares* of the *first* and *last* ordinates add *four* times the *sum* of the *squares* of all the *even* ordinates, and *twice* the *sum* of the *squares* of all the *odd* ordinates; *multiply* this result by the common distance between the ordinates and by the circular measure $\frac{3.1416\ \varphi}{180}$ corresponding to the angle through which the vessel has rolled or has been inclined;* *divide* by *six*, and the volume of the wedge is obtained (nearly).

The following is a method of finding the centre of gravity of a vessel when fully equipped for sea, the rule being known as "Abethell's rule," and applicable whenever a ship is taken into dock with the under side of her keel deviating from parallelism with the upper surface of the blocks, which is nearly always the case.

Suppose by the falling of the water in the dock the after extremity of the keel to come first in contact with the blocks; then, as the water continues to fall, the after body is gradually forsaken by the water and the fore body further immersed, a constant equilibrium being maintained between the total weight of the ship and the pressure of the water against the immersed part of the body, until the ship is aground on the blocks, fore and aft. At any intermediate instant the ship may be considered as a lever of the second kind, of which the fulcrum is the transverse line or point of contact of the keel and after block, and the power and weight, the weight of the immersed volume and that of the ship respectively, each acting in the vertical line passing through its centre of gravity. As we can by mensuration and calculation from the draft of the ship easily find its weight, as

* In fig. 26 $\varphi = 10°$.

also its immersed volume, and the perpendicular distance of the line of pressure from the fulcrum,—therefore, in the equation of the moments the distance of the vertical line passing through the centre of gravity of the ship is the *only* unknown quantity, and may be readily determined. AN (fig. 34) represents the water-line corresponding to the floating position of the ship, and KL the observed water-line just previously to the *fore* part of the keel touching the blocks. The line PBO, perpendicular to AN, passes through the centre of gravity of the displaced volume AFMN, and consequently through that of the ship.

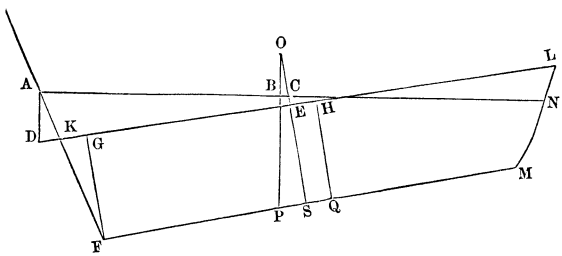


Fig. 34.

Draw QH through the centre of gravity of the volume KFML, perpendicular to KL, and FG through the fulcrum F, parallel to QH. Then by putting the total displacement AFMN $= V$, KFML $= v$ and GH $= b$; if the line SEO, parallel to QH, be drawn at the distance GE from G equal to $\frac{bv}{V}$, it will, as well as PBO, pass through the centre of gravity of the ship, which will be in O, the point of their intersection.

To obtain from these considerations a general expression for the perpendicular distance of the point O from the water-line AN, draw AD perpendicular to EG, and meeting it when produced in D; and having calculated the values of AB and GE, put AB $= a$, DE or DG + GE $= d$, and the angle of inclination between the water-lines AN and KL $= \triangle$; then BO $= \left(\frac{d}{\cos\triangle} - a\right)\frac{1}{\tan\triangle}$; which must be set off upon the perpendicular PBO, above or below AN, according as $\frac{d}{\cos\triangle}$ is greater or less than a.

The curve of vertical sections may also be used for determining the position of the centre of buoyancy, etc. The principles employed are those enunciated in Rules I., II., V., VI., etc., where the areas, moments, etc., are set off at their respective distances on the base line; that is, the load water-line, divided by a constant quantity corresponding to the depth of the volume of water displaced. Thus, the displacement is considered as divided longitudinally into two equal portions, which is equivalent to dividing the base line of the sectional areas into two equal portions; and if AC (fig. 35) be the load water-line which is bisected in D, CBADC is taken to represent half the displacement. If we set off the vertical areas as ordinates at equal distances apart, the curve CBA, passing through their extremities, will be that of the curve of sectional areas, and the centre of buoyancy may be determined by the usual methods.

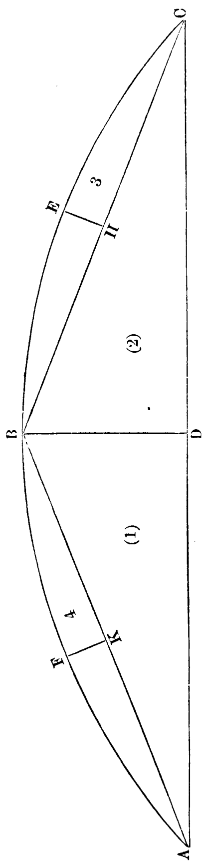


Fig. 35.

To ascertain the amount of *weight* the ship can receive on board and the relative positions of the weights, it is only necessary to construct on the *same base* a curve of sections for the load displacement and light displacement. The difference between the areas will be the representative area of the weights.

To Construct a Scale of Displacement.—Calculate from the plans of the vessel the displacement in tons at *each* water-line. Draw a perpendicular line to represent the mean draught of water, and set off on this line, by means of a scale of parts, the depths of the several water-lines. Now draw horizontal lines, at the points thus obtained, perpendicular to the assumed scale for depth, and having determined a scale to denote the tons (ascertained by calculating the displacement for each water-line as above), set off on each horizontal line, by this scale, the displacement in tons due to each water-line. A curve passed through these points will be the curve of displace-

ment; and the displacement for any intermediate draft can be ascertained readily from the scale.

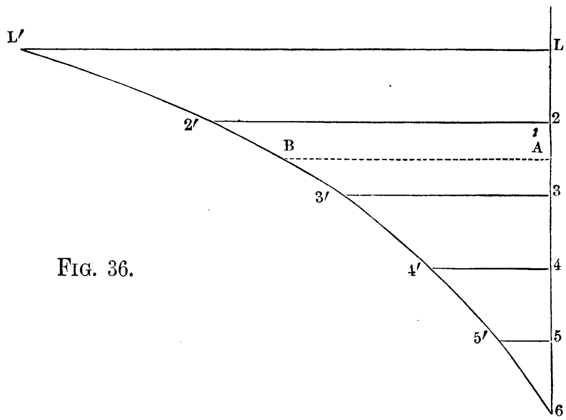


FIG. 36.

In fig. 36 the line L6 represents the depth as above; LL′ the displacement tonnage (by scale of parts) at the load water-line; 2 2′ the displacement at the second water-line, and so on. Now, to ascertain any intermediate displacement at a draft A6, it is only necessary to draw the line AB perpendicular to L6; measure the distance AB, and transfer it to the scale of tons; the result is the displacement in tons at the required draft of water.

To find the "Tons per Inch of Immersion."—It is only necessary to divide the area of the given water-line in square feet by 35, which will give the *tons displacement per* FOOT *of immersion.* This result, divided again by 12, gives the *tons displacement per* INCH *of immersion* at the given water-line.

The student has now been shown the method of ascertaining—

1. The displacement in cubic feet and tons.
2. The area of any section, vertical or horizontal.
3. The centre of gravity of any section.
4. The position of the centre of gravity of displacement.
5. The position of the centre of gravity of the vessel.
6. The height of the meta-centre above the centre of buoyancy.
7. The volume of the "shoulders."
8. The method of using the curve of sections.
9. The mode of constructing a scale of displacement; and, lastly,

TABLE XXIX.—*Calculations for a Schooner Yacht of Eighty Feet Length.* (Figs. 26, 27 and 28.)

a	b	c	A d	P e	Q f	P g	A h	i	k	l	m	n	o	p	r	s	t	u	v	w
			keel	wl. 4	wl. 3	wl. 2	lwl. 1													
			1	4	2	4	1													
A 1	2.000	1	.3	.3	.3	.3	.3													
	r		.3	1.2	.6	1.2	.3	3.6	2.4	2.4	0	......	.3	......	.3	.3	.3	.3	......	.03
P 2	2.047	4	.3	.6	1.4	2.1	2.8													
	r		.3	2.4	2.8	8.4	2.8	16.7	11.4	45.6	1	45.6	11.2	11.2	2.8	2.5	2.6	10.4	10.4	21.95
Q 3	2.094	2	.3	1.3	2.7	4.1	5.5													
	r		.3	5.2	5.4	16.4	5.5	32.8	22.9	45.8	2	91.6	11.0	22.0	5.9	4.8	5.4	10.8	21.6	166.37
P 4	2.141	4	.3	1.8	4.1	6.1	7.8													
	r		.3	7.2	8.2	24.4	7.8	47.9	34.2	136.8	3	410.4	31.2	93.6	8.4	7.0	7.7	30.8	92.4	474.55
Q 5	2.188	2	.3	2.0	5.1	7.8	9.4													
	r		.3	8.0	10.2	31.2	9.4	59.1	43.1	86.2	4	344.8	18.8	75.2	9.8	8.7	9.2	18.4	73.6	830.50

P 6	2.235	4	.3	2.2	6.1	9.4	10.3														
	r		.3	8.8	12.2	37.6	10.3	69.2	51.5	206.0	5	1030.0	41.2	206.0	10.7	9.9	10.3	41.2	206.0	1092.73
Q 7	2.282	2	.3	2.3	6.4	9.8	10.7														
	r		.3	9.2	12.8	39.2	10.7	72.2	54.9	109.8	6	658.8	21.4	128.4	11.0	10.4	10.7	21.4	128.4	1225.04
P 8	2.329	4	.3	1.7	5.3	8.7	10.3														
	r		.3	6.8	10.6	34.8	10.3	62.8	48.7	194.8	7	1383.6	41.2	288.4	10.8	9.7	10.3	41.2	288.4	1092.73
Q 9	2.376	2	.3	1.1	3.6	6.6	9.1														
	r		.3	4.4	7.2	26.4	9.1	47.4	37.5	75.0	8	600.0	18.2	145.6	10.3	8.2	9.2	18.4	147.2	753.57
P 10	2.423	4	.3	.8	1.9	4.0	7.0														
	r		.3	3.2	3.8	16.0	7.0	30.3	24.5	98.0	9	882.0	28.0	252.0	8.7	5.8	7.2	28.8	259.2	343.00
A 11	2.470	1	.3	.4	.7	1.2	3.2														
	r		.3	1.6	1.4	4.8	3.2	11.3	9.3	9.3	10	93.0	3.2	32.0	4.4	2.5	3.5	3.5	35.0	32.77
		0	3.3	14.2	37.1	59.8	76.1		340.4	1009.7		5539.8	225.7	1254.4				225.2	1262.2	6033.24

SECTION No. I. .25 feet abaft fore end of load water-line; distance between the vertical sections 7.5 feet (r').
SECTION No. XI. 4.75 before after end of load water-line; keel below rabbet 1 foot.

the mode of finding the number of tons required to immerse a vessel *one inch* at any given water-line.

To make these calculations is not difficult, but it is, for some vessels, somewhat laborious. A little method and arrangement, however, shortens the process amazingly, and the plan of calculation most applicable to a small vessel like the yacht in question is as follows:

On the drawing of the vessel fix No. 1 section in the sheer plan (fig. 27) at some determinate place, such as the fore end of the load water-line; then divide the length of that line into any uneven number of equal parts by lines perpendicular to it, which will represent the vertical sections. Draw a body plan of these sections to the outside of the plank (fig. 26), having the load water-line as a base in both plans. Divide the distance from the load water-line to the line of the lower edge of the rabbet of the keel continued at No. 1 section into an odd number of equi-distant parts, as five inclusive; also divide the corresponding distance at the aftermost section into a like number of equi-distant parts. Draw lines from No. 1 section to the aftermost section joining these divisions, and transfer the heights of the intersections of these lines with the sections to the body plan. A table must now be ruled similar to the accompanying form, and the half-breadth of each section at each water-line, measured from the body plan, inserted in its proper place in the table.* (See Table XXIX.)

A description of each column is as follows:

a. The number of the vertical section.

b. The distance between the water-lines at each section respectively. It is thus found: the distance of the load water-line to the lower edge of the rabbet of the keel at No. 1 section is 8 feet, and at No. 11 section it is 9.875 feet; then, as No. 1 and No. 11 sections are 75 feet apart, it follows that the difference of draft of water in 75 feet is 1.875 feet, and the difference between each section when (as in this case) they are 7.5 feet apart is—

$$\frac{1.875 \times 7.5}{75} = .1875.$$

As there are four water-lines, the distance between them at each suc-

* Or the ordinates may be measured from the half-breadth plan.

ceeding section will be increased by the fourth part of $.1875 = .047$ feet. At No. 1 section the water-lines are 2 feet apart; at No. 2, $2 + .047 = 2.047$ feet apart, and so on.

c. The number by which the ordinates are to be multiplied in finding the displacement by horizontal sections.

d. The ordinates of the lowest longitudinal section, or half siding of the keel at each section.

e. The ordinates of the lowest water-line.

f. The ordinates of the third water-line.

g. The ordinates of the second water-line.

h. The ordinates of the load water-line.

i. The sums of the ordinates as multiplied.

k. The half areas of the sections $= \frac{i \times b}{3}$; thus, for No. 7 section, $\frac{72.2 \times 2.282}{3} = 54.9$ square feet.

l. The half areas of the sections multiplied by the numbers in column *c* respectively; the sum of the column *l* multiplied by one-third of the common interval between the sections gives one-half the displacement in cubic feet, or $\frac{0l \times 7.5}{3} \times 2 =$ whole displacement, which, divided by 35, gives the displacement in tons of that part of the vessel included within the limits of the calculation,* thus—

$$1009.7 \times \frac{7.5}{3} \times 2 = 5048.5 \text{ cubic feet} = 144.2 \text{ tons.}$$

m. The multipliers for finding the distance of the centre of gravity of displacement from No. 1 section.

n. The products of $l \times m$, then $\frac{0n}{0l} \times$ common interval between the sections, = distance the centre of gravity of displacement is from No. 1 section or $\frac{5539.8}{1009.7} \times 7.5 = 41.2$ feet.

o. The ordinates of the load water-line multiplied by the numbers in column *c* respectively; the sum of these products, multiplied by one-third of the common interval between the sections, will give half the area of the load water-line, thus: $0o \times \frac{7.5}{3} =$ the half area of the

* To this must be added the keel, rudder, etc.

load water-line, or $225.7 \times \frac{7.5}{3} \times 2 = 1128.5$ square feet = the whole area.

p. The products *m* and *o* for finding the distance of the centre of gravity of the load water-line from No. 1 section. The sum of these products, divided by the sum of column *o*, and the quotient multiplied by the common interval, gives the required distance, or $\frac{0p}{0o} \times 7.5 =$ the distance of the centre of gravity of the load water-line from No. 1 section $= \frac{1254.4}{225.8} \times 7.5 = 41.68$ feet.

r. The ordinates of the *immersed* water-line when the vessel is inclined 10°.

s. The ordinates of the *emersed* water-line when the vessel is inclined 10°.

t. The half sums of *r* and *s*.

u. The products of *t* and *e*. The sum of this column, multiplied by one-third of the common interval, gives one-half of the area of the inclined water-line, thus: $0u \times \frac{7.5}{3} \times 2 =$ the whole area, or $225.2 \times \frac{7.5}{3} \times 2 = 1126$ square feet.

v. The products of *u* and *m* for finding the distance of the centre of gravity of the inclined water-line from No. 1 section; then $\frac{0v}{0u} \times 7.5 =$ distance required, or $\frac{1262.2}{225.2} \times 7.5 = 42.03$ feet.

w. The cubes of the ordinates of the load water-line required for finding the height of the meta-centre above the centre of gravity of displacement. The sum of this column, multiplied by two-thirds of the common interval, and the product divided by the number of cubic feet in the displacement, gives the height of the meta-centre; thus $\frac{6033.24}{5048.5} \times \frac{7.5}{3} \times 2 = 5.975 =$ height of the meta-centre above the centre of gravity of the displacement.

To find that part of the displacement which is before the centre of gravity, this latter point being 41.2 feet abaft No. 1 section, it will be 3.8 feet before No. 7. The displacement between Nos. 1 and 7, taken from column *l*, is 2888.5 cubic feet; from this must be sub-

tracted the cubical content of that part between No. 7 and the centre of gravity = area of No. 7 $\times$ 3.8 = 109.8 $\times$ 3.8 = 417 cubic feet; thus making the displacement before the centre of gravity 2471.5 cubic feet; and the displacement abaft that centre will be the whole displacement *minus* 2471.5 = 2577 cubic feet.

The distance of the centre of gravity of the fore body from the centre of gravity of displacement will be for the part between Nos. 1 and 7, from column *n*—

$$\begin{array}{rcl}
2.4 \times 0 & = & \\
45.6 \times 1 & = & 45.6 \\
45.8 \times 2 & = & 91.6 \\
136.8 \times 3 & = & 410.4 \\
86.2 \times 4 & = & 344.8 \\
206.0 \times 5 & = & 1030.0 \\
54.9 \times 6 & = & 329.4 \\
\hline
576.9 & & 2251.8
\end{array}$$

$\frac{2251.8}{576.9} = 3.9$, which multiplied by the common interval 7.5 = 29.25 feet = distance the centre of gravity of that part between Nos. 1 and 7, is from No. 1 section. The centre of gravity of the part between No. 7 and the centre of gravity of displacement will be $45 - \frac{3.8}{2} = 43.1$ feet from No. 1, and combining these distances we have

$$\begin{array}{rcl}
\text{Cubic Contents.} & & \text{Moments.} \\
2884.5 \times 29.25 & = & 84371 \\
417.0 \times 43.1 & = & 17972 \\
\hline
2467.5 & & 66399
\end{array}$$

$\frac{66399}{2467.5} = 26.9$ feet the distance of the centre of gravity of the fore body from No. 1; then 41.2 — 26.9 = 13.9 feet, which will be the distance of the centre of gravity of the fore body from the centre of gravity of displacement.

For the after body a similar method is pursued, except that in this case the smaller moment is positive. The result gives the distance as 13.5 feet.

To find the distance the centre of gravity of displacement is below the load water-line, multiply the sums of the products of the ordi-

nates of the water-lines (multiplied by the numbers 1, 4, 2, 4, 1 respectively) by 0, 1, 2, 3, 4 respectively, commencing from the load water-line downward; the sum of these products divided by the sum of the first products, and the quotient multiplied by the distance between the water-lines at the centre of gravity of displacement, will give the required distance, thus:

Load water-line	76.1 × 1 =	76.1 × 0		
Water-line (2)	59.8 × 4 =	239.2 × 1 =	239.2
" (3)	37.1 × 2 =	74.2 × 2 =	148.4
" (4)	14.2 × 4 =	56.8 × 3 =	170.4
Keel.............	3.3 × 1 =	3.3 × 4 =	13.2
		449.6	571.2

The distance between the water-lines at the centre of gravity is thus found: *as* the length between the extreme sections *is to* the difference of depth in that length, *so is* the length from No. 1 section to the centre of gravity *to the* difference in depth due to that part of the length; or,

Feet.		Feet.		Feet.		Feet.
80	:	2	: :	41.2	:	1.03

This, added to the depth at No. 1 section, gives the whole depth at the centre of gravity $= 8 + 1.03 = 9.03$ feet, which, divided by 4 (the number of water-lines), = the distance the water-lines are apart at the centre of gravity $= 2.26$ feet.

Then $\frac{571.2}{449.6} \times 2.26 = 2.871$ feet, the required distance.

The above method of finding the distance between each water-line is not always strictly correct, because the centre of gravity of displacement longitudinally may not be exactly at the point used (41.2); but the error is so trifling as to be practically insignificant. In the foregoing calculations the keel is omitted; its dimensions being—length, 80 feet; depth, 1 foot; and breadth, 7 inches. The cubic content is therefore 48 feet.

There is also a trapezium between No. 2 section and the stern-post; the depth, 10 feet; length, 5 feet; and mean breadth, 1 foot = 50 cubic feet. The total displacement is therefore—

$$5048.5 + 48 + 50 = 5146.5 \text{ cubic feet} = 147 \text{ tons.}$$

A full understanding of the reason for each step in the process of calculation greatly facilitates the proceeding.

The first and principal object is to find the area of each vertical section. If the section were a rectilinear triangle, nothing more would be required than to take the sum of half of the two extreme ordinates and multiply it by its depth; but the sections of a ship have one side of the triangle curvilinear, and therefore this easy method of finding the area would give an erroneous result, as it does not include the space contained between the right line and the curve.

Of the three methods given for obtaining a more correct area, the "Short" rule, or third method, is the simplest known, though it is too inaccurate for most cases.

Applying the "Short" rule to Section 7 of the table, we have—

Ordinate 1...	.3	Ordinate 2...	2.3
" 5...	10.7	" 3...	6.4
2)	11.0... A	" 4...	9.8
$\frac{A}{2}$..............	5.5		18.5... Q
	18.5		
	24.0		
r................	2.282 distance between the ordinates.		
	54.768 required half area,		

which is slightly different from the tabulated area.

But it is better to use "Simpson's" rule, as by it we would have—

Ordinate 1...	0.3	Ordinate 2....	2.3	Ordinate 3....	6.4
" 5....	10.7	" 4....	9.8		2
A..................	11.0	P..............	12.1	2 Q...........	12.8
	48.4		4		
	12.8	4 P...........	48.4		
	72.2				
r....................	2.282 the distance between the ordinates.				
3)	164.76				
	54.92 the required half area,				

as determined from the formula in which the

Area $= [A + 4P + 2Q]\frac{r}{3}$

the curve bounding the area being supposed to be a portion of a common parabola.

The second rule may be applied in a similar manner; but the area must be divided into that number of equal divisions which will be a multiple of 3, so as to make the number of *ordinates* a multiple of 3 with one added.

As before stated, in calculating areas or displacement when the water-lines or sections are very round, or when the vertical sections are more than *five feet* apart, either "*Simpson's*" rule or the "*Three-eighths*" rule should be employed; but when the lines are tolerably straight, and the ordinates are less than *five feet* apart, the "*Short*" rule will give a result sufficiently accurate, and from its greater simplicity is to be preferred; or the two rules may be combined with advantage, as when the vertical sections are much curved, but the water-lines rather straight; thus, to calculate the displacement, taking the half areas found by "Simpson's" rule from column *k*, Table XXIX.:

Section 1.................	2.4 (half)	
" 2.................	11.4	
" 3.................	22.9	
" 4.................	34.2	
" 5.................	43.1	
" 6.................	51.5	
" 7.................	54.9	
" 8.................	48.7	
" 9.................	37.5	
" 10.................	24.5	
" 11.................	9.3 (half)	
	334.55	
	7.5	distance between the sections.
	2509.125	half displacement.
	2	
	5018.25	whole displacement.

When the water-lines are parallel and equi-distant, the displacement may be found by taking the areas of the water-lines and apply-

ing either rule to them; though in the case of the yacht whose displacement we are calculating, the water-lines not being equi-distant and parallel, it is almost impracticable to obtain an exact result in this way, though a tolerably good approximation may be obtained, as in the following example (the distance between the water-lines being supposed to be that at the middle of the length, or at No. 6 section), by taking the areas of the water-lines by the "Short" rule, and completing the calculation by Simpson's *rule*, thus:

Keel.............		3.0 × 1 =	3.0
Water-line	(4)	14.2 × 4 =	56.8
"	(3)	37.1 × 2 =	74.2
"	(2)	59.5 × 4 =	238.0
Load water-line		74.7 × 1 =	74.7

446.7
7.5 common interval.
3) 3350.25
1116.75
2.235 { distance between the water-lines.
2495.9 half displacement.
2
4991.8 whole displacement.

which differs very little from the more laborious process, and, if not quite so correct, is useful as a *check* on the *accuracy* of the work.

In calculating the distance of the centre of gravity of displacement from No. 1 section, it is required to find the *moment* of each section, which is its distance multiplied by its contents; the sum of these moments divided by the sum of the contents will give the distance required; but as this process involves a large number of figures, it is curtailed by multiplying the *area* of each section by the number of its place from No. 1: if then the sum of the areas so multiplied is divided by the sum of *all* the areas, and the quotient is multiplied by the distance between the sections, the same end is gained with a less amount of figuring.

The positions of the other centres of gravity are calculated on the same principle.

The height of the meta-centre above the centre of gravity of displacement being a measure of the comparative stability of the ship, is estimated from the expression $\frac{2}{3}\int\frac{y^3dx}{\mathrm{D}}$, in which

y = the ordinates of the half-breadth load water section.

dx = the increment of the length of load water section.

D = displacement in cubic feet.

The ordinates are taken from the table (column h) and cubed (column w), the calculation being made in accordance with the rules previously given.

It will thus be seen that the calculations for a small vessel are extremely simple and easy of performance; indeed any one tolerably well versed in simple arithmetic may complete the whole of the calculations for a vessel of, say, 200 tons *in less than an hour*, when equidistant vertical sections and the water-lines at their proper height are drawn in the half-breadth and body plans.

It now only remains to find the area and position of the centre of effort of the sails.

The area of the jib is found as follows: The *luff* being the hypothenuse, the *foot* the base, the *after leech* the perpendicular; from the clew let fall a perpendicular to the luff, multiply the length of luff by length of this perpendicular and divide by 2; the result is the required area.

The centre of gravity (or of effort) of the jib is found by bisecting the length of the luff, then two-thirds the distance from this point to the clew, set off on a straight line, is the position of the centre of gravity required.

The area of the mainsail is ascertained by dividing the whole sail into two triangles by a diagonal, finding the area of each triangle and adding them together.

To find the centre of gravity of the same sail, divide it by lines into four triangles, find the centre of gravity of each, then draw lines from these centres—where they intersect is the centre of gravity of the whole sail.

The area of the sails of the schooner (fig. 29) calculated in the foregoing mannner will be as follows:

	Areas in sq. feet.
Jib	992
Foresail	1290
Mainsail	2028
	4310

The position of the centre of effort as to height above the water-line is found by multiplying the area of each sail by the perpendicular distance of its centre of gravity from the water-line, then dividing the sum of these products or *moments* by the sum of the areas; the quotient is the required distance, thus:

	Areas in sq. feet.	Height of centre of gravity above load water-line in feet.	Momenta.
Jib.......	992	× 25.6	= 25395.
Foresail	1290	× 32.0	= 41280.
Mainsail	2028	× 31.6	= 64084.
	4310		) 130759.
			30.33

or the height of the centre of effort above the load water-line.

The distance of the centre of effort from any perpendicular to the water-line, considered as an initial point, is found by dividing the difference of the moment of sail before and abaft that perpendicular by the area of sail: according as the excess of the *momenta* is before or abaft the perpendicular, so will the position of the centre of effort be—thus:

	Areas in sq. feet.	Distance of the centre of gravity from a perpendicular at the centre of the longitudinal section in feet.	Momenta.
Jib.......	992	× 35.1 before	= — 34819
Foresail	1290	× 6.0 "	= — 7740
Mainsail	2028	× 27.5 abaft	= + 55770
	4310		

or [55770 — 42559] ÷ 4310 = 3.06, which is the distance the centre of effort of all the sails is *abaft* the centre of gravity of the immersed longitudinal section.

To find the Centre of Gravity from a Model.—It is only necessary to dispose the model, which, for great accuracy, may be made without screws or dowels, successively in two positions of equilibrium. Insert a tack in the surface of the plane representing the middle line

near the extreme point of intersection of rail with knighthead, from which suspend the model by a line; hang a plummet from the same point of suspension, and, when at rest, mark the intersection of the line with the plane; the model may now be suspended from the other extremity, at the intersection of the rail with the stern, and the centre of gravity will be found on the plane at the intersection of the two lines thus found.

The same process may be resorted to in determining the centre of buoyancy, by separating the model at the load, or any line of flotation below which the centre of displacement is required.

The *displacement* is obtained by the following simple method: A water-tight vessel, having a small pulley in the bottom, is filled with distilled water in sufficient quantity to float the model, which is placed in the fluid and drawn down by the pulley to its proposed line of flotation. A faucet previously arranged permits the exact amount of water displaced to run out into the bowl of a nicely adjusted pair of scales, and the weight of water displaced by the half model; and by an easy computation the whole ship may be thus obtained.

FORM OF CONTRACT FOR BUILDING A SCHOONER YACHT OF 165 TONS, BUILDERS' MEASUREMENT.

It is this day agreed between A. B. of ——, and C. D. of ——, ship-builder; the said C. D. to build and complete the hull of a schooner yacht, according to the following dimensions and proportions, for the sum of $, to be paid in three separate portions; viz., the first payment of $ to be made upon signing this agreement; the second payment of $ to be made when the vessel is completely timbered and planked and the upper deck laid, and the remainder of the sum to be paid when the vessel is delivered over to the said A. B.; and the said C. D. agrees to complete the said yacht and deliver over the same to the said A. B. on or before the day of , 186 , and in default of so completing and delivering over, he agrees to forfeit the sum of $ per day for each and every day the said yacht is not completed and delivered over to the said A. B. after the above-named day; and it is further agreed that the said A. B. shall appoint a surveyor to overlook the work and material used in the building of the said yacht, and that the said yacht shall be built to the satisfaction of the said surveyor; and that

no payment of money shall be due until the said surveyor shall have signified in writing that the workmanship and material meets with his approval; and the said surveyor shall at all times be permitted to have access to the said vessel during the progress of the work; and that no charge shall be made by the said C. D. for any work or material not specified hereafter, or for any alteration of any part of the dimensions, materials or fittings, unless a written order for such extra work be given by the said A. B. or his surveyor; and that any such order for extra work shall state the number of days over the day of , 186 , which shall be allowed to the said C. D. to finish the said vessel, in consideration of such extra work or alteration; and if no mention of such additional time is made in writing, then the original date is to be considered as the day for completing the said vessel as aforesaid.

Dimensions.

	Feet.	Inches.
Length between the perpendiculars	80	0
Length of keel for tonnage	67	$1\frac{1}{4}$
Breadth, extreme	21	8
Breadth, moulded	21	0
Depth in hold	—	—

Burthen in tons, $164\frac{92}{95}$, builders' measure.

Specifications.

Keel.—To be of live oak in not more than three pieces, sided amidships 8 inches, tapered at the ends to 7 inches, moulded 10 inches, to have 6 inches whole wood below the rabbet, scarphs 3 feet long, caulked and bolted with four $\frac{1}{2}$-inch copper bolts.

False keel.—Of white oak, thick 4 inches.

Keelson.—Of live oak, sided 8 inches, moulded 8 inches, bolted through every floor timber with one $\frac{5}{8}$-inch copper bolt, scarphs same as keel.

Stem.—Of live oak, sided at the head 8 inches, at the foot 7 inches, moulded at head 10 inches, whole wood before the rabbet 4 inches, scarphs as keel.

Apron.—Of live oak, sided as the stem, moulded not less than 8 inches.

Knightheads.—Sided 6 inches, moulded as the frame, bolted through the stem with $\frac{5}{8}$-inch iron.

Stern-post.—Of live oak, sided at the head 8 inches, at the heel 7 inches, moulded at head 10 inches, at heel 12 inches.

Inner post.—Of live oak, sided as post, moulded as per draft.

Deadwood.—Of live oak, forward and aft as may be required, with deadwood knees well bolted with $\frac{3}{4}$-inch copper.

Frame.—Moulded at cutting down................................ 8 inches.

Moulded at cutting down					8	inches.
" floor heads					7	"
" half floor heads					$6\frac{1}{2}$	"
" first futtock heads					6	"
" planksheer					4	"
Floors sided amidships	8 inches,	forward	and	aft	7	"
Half floors	"	7	"	"	" 6	"
1st futtocks	"	6	"	"	" $5\frac{1}{2}$	"
2d futtocks	"	5	"	"	" $4\frac{1}{2}$	"

The timbers of the frame to be of live oak, free from sap or defect. The floors and half floors to be bolted together with $\frac{5}{8}$-inch square iron, the rest of the frame with $\frac{1}{2}$-inch square iron. To have two hawse timbers of live oak on each side, bolted with $\frac{5}{8}$-inch iron, sided 9 inches at head.

To have a transom, or to be framed at the counter, as required.

Wales.—To have two strakes of live oak or white oak wales, together wide 9 inches.

Plank.—The eight lower strakes to be of white oak, 3 inches thick; the remainder to be of yellow pine, 3 inches thick; to be fastened with copper $\frac{1}{2}$ inch in diameter, clenched through every third timber, and a $\frac{1}{2}$-inch metal dump 7 inches long in the remaining timbers. All the plank to be wrought in parallel strakes, the butts to have not less than 6 feet shift, and three strakes of plank to intervene between two butts placed above one another on the same timber.

Shelf.—Of yellow pine, deep 8 inches, wide at the upper side 6 inches, at the lower side 3 inches, bolted with $\frac{5}{8}$-inch copper.

Deck Beams.—Of yellow pine, sided 6 inch, moulded 6 inch, secured to the shelf with one $\frac{1}{2}$-inch iron bolt at each end. The bitt, mast and two other beams to have an iron hanging knee at each

end, each weighing 28 lbs., and fastened with three iron ½-inch bolts through the beam arm, and three copper ½-inch bolts through the side arm.

Iron crutches and deck hooks as directed.

Waterway.—Of yellow pine, deep 4 inches, wide 8 inches.

Planksheer.—Of yellow pine, 4 inches thick and 6 inches wide.

Roughtree stanchions.—Sided at planksheer 5 inches, at rail 3½ inches of white oak, wide 5 inches, thick 3 inches.

Coamings and headledges.—Of live oak or mahogany, thick 3 inches.

Deck.—Of 2½-inch yellow pine, each strake not more than 4 inches wide, fastened with metal spikes 6 inches long, the strakes at and about the windlass, masts, etc., to be of live oak or white oak as directed.

Platform Beams.—Of yellow pine, 4 inches by 4 inches.

Platform.—Of 2-inch pine.

Ceiling.—Below the platform of live oak, the remainder of yellow pine 1 inch thick, fastened to the timbers with galvanized iron spikes, 4 inches long.

Pall Bitts.—8 inches square, to run down and secure to the keelson as may be directed.

Carrick Bitts.—Sided 3 inch, not less than 10 inches wide, properly kneed, bolted and secured.

Windlass.—Complete with palls, pinion and wheel-work, etc.; if a patent windlass is required, it is to be paid for in addition.

Channel work, chain plates, bolts, dead-eyes, etc., as required.

Mast Partners.—To be properly framed.

Rudder.—To be made and bolted as required, the head to be round, 8 inches diameter. To find and fix three pairs of proper metal pintles and braces; the rudder head to fit and work in a metal collar let into the deck.

Tiller.—Of wood or iron.

Bulwarks.—Of yellow pine or chestnut, 1 inch thick, rabbeted, each strake 3 inches wide.

Catheads.—As required, with sheaves, whiskers to jibboom, guy, etc.

Skylights and deck fittings complete, of mahogany, as required.

Mast steps.—On the keelson 5 feet long, 4 inches deep.

Cabin fittings.—The bulkheads of 1 inch pine, rabbeted, the main-cabin to be fitted with panels of maple wood with mahogany

styles and rails, French polished; the after cabin fitted with damask hangings.

Caulking.—The vessel to be thoroughly caulked with the usual number of threads of oakum, and the seams payed with pitch and scraped; the deck to be payed with marine glue.

To find and fit all necessary pin-racks, belaying bitts, cleats and pins to fore and mainmasts, also cleats, sheaves, eye-bolts, etc., as required for a schooner; boat-davits, hawse-pipes, chain-cable hoods, two pumps and pipes, companion ladders, etc.

The bottom of the vessel to be coppered with 18-ounce copper, from 6 inches above the load water-line downward, the fore part of the stem and under side of the keel to be covered with 32-ounce copper.

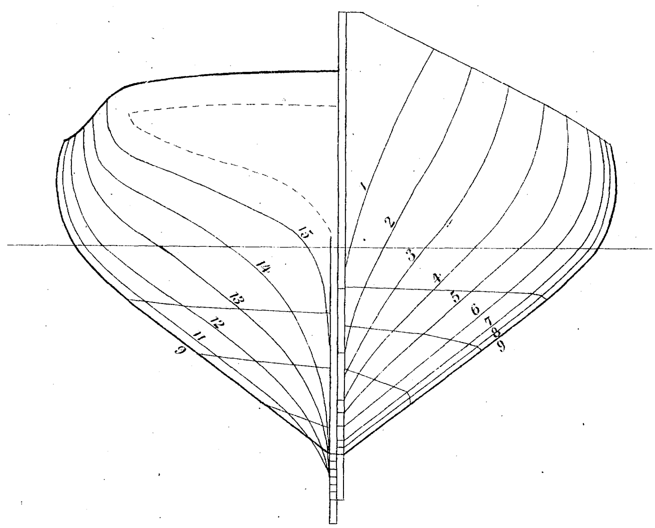
To provide a new gig boat 25 feet long, with oars, rudder, thwarts and gratings complete; also a new dingy 15 feet long, complete.

The whole of the materials and workmanship to be of good quality, and to the satisfaction of the surveyor; and the vessel to be completed as to hull, cabin and deck-fittings by the builder.

The bulwarks to have three coats of paint inside and out, and the cabins and underside of the deck to receive three coats of paint as directed.

(Signed) A. B.
C. D.

Fig. 37.



YACHT
AMERICA

Scale $\frac{1}{8}$TH of an Inch to a Foot.

Fig. 38.

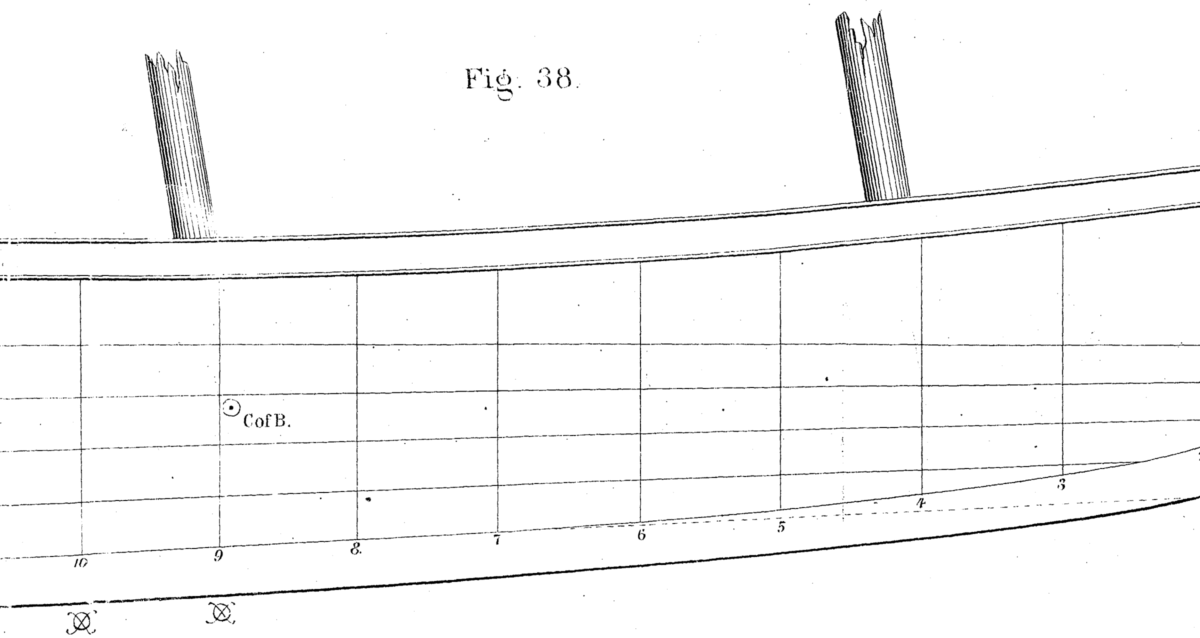
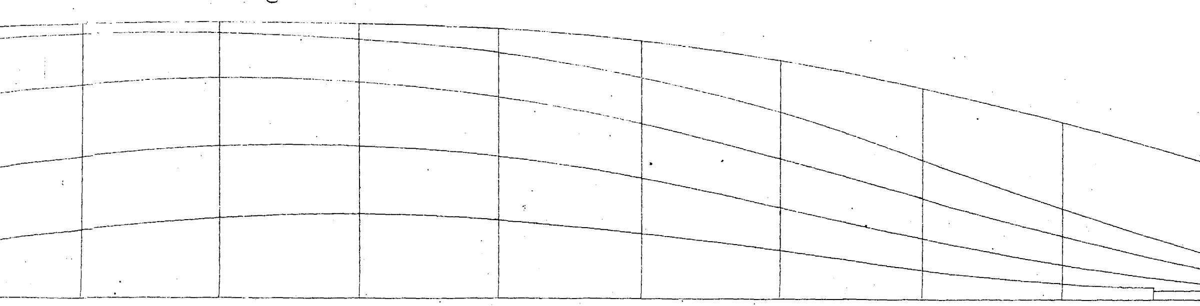
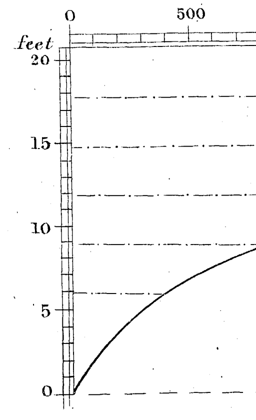


Fig. 39.



DRAUGHT OF AN IRON SCREW STEAM SHIP.



Dimensions

	feet
Length between perpendiculars	*290.*
Breadth extreme	*41.*
Depth amidships (from top of keel)	*29.*

Burthen in tons *2373 $\frac{6}{94}$ B M*
Horses power (nominal) *450*

Fig. 41.
SHEER PLAN

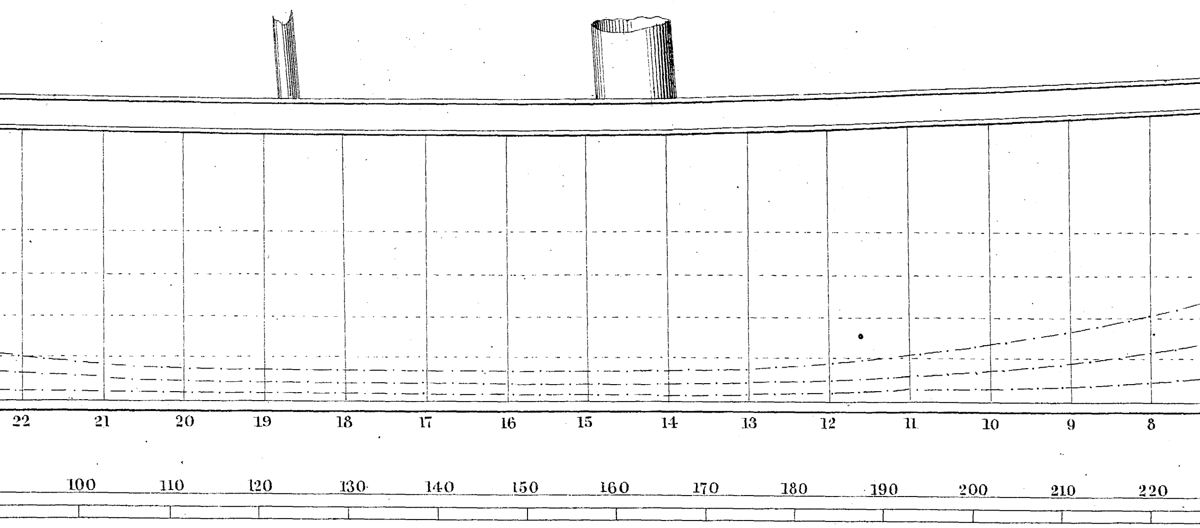
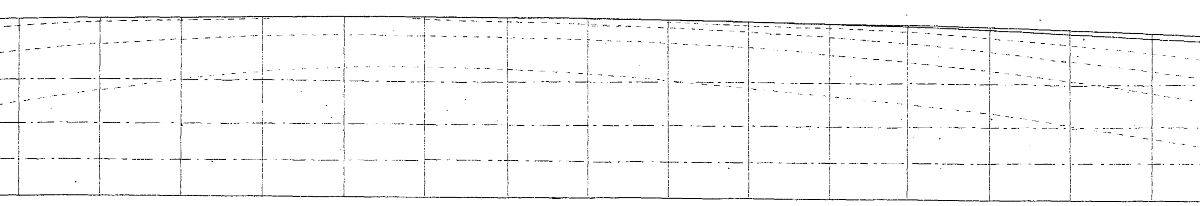


Fig. 42.
HALF BREADTH PLAN



CHAPTER XXIX.

SUMMARY OF NAVAL DESIGN ON THE "WAVE" PRINCIPLE.

Let the constructor take, for example, the scheme on page 34 (Chapter V.), where the ship is to have 90,000 cubic feet of gross capacity and 1500 tons gross weight. It happens to be a merchant steamer, and the question is: What are the extreme dimensions of a ship able to do this work?—observing that the work is to be done at ten (10) knots per hour. The nominal tonnage of a ship or "roomage" being 100 cubic feet to a ton, this vessel will be nominally a 900-ton ship; but as this gives nothing in regard to the *dimensions* of the vessel, the naval architect is left to draw these elements from his own resources and judgment. He has one element, however, of a definite nature—viz., that the total dead weight to be carried is 1500 tons.

By referring to Chapter VI. and VII., he will find the immediate means of approximating to the dimensions of his vessel. As Chapter VI. contains the principles of displacement, he can there find by Table III. what the ship will have to be in order to carry the weight of 1500 tons. She *must* displace 75,000 cubic feet of sea water. Now commence by supposing her to be a rectangular box, of which the draft is to be 15 feet (the limit assigned); he will find that such a box must be 200 feet long and 25 feet wide when immersed to 15 feet, in order to carry the assigned weight. These, then, are the dimensions (*about*), having as yet no assigned *shape*. This being the gross under-water body of the ship, there remains for the over-water body only 15,000 cubic feet. The designer will at once see that this quantity is too small for an over-water body, as in the rectangular box the top would only be three (3) feet above water. In order to be safe, the architect will have to enlarge the over-water body; the under-water body he cannot diminish. He will find in the following

Chapter (VIII.) that the over-water body is too small, both for *stability* and *seaworthiness.*

Passing to the various cross sections presented in Chapter XIII., he will come upon two forms (figs. 6 and 7) which are sufficiently near the usual forms of *midship section* of merchant steamers to serve as a type for a first approximation. A sailing vessel would do better with fig. 8 or probably fig. 9; but cargo-carrying and steam-power being the main elements, fig. 6 or fig. 7 is better for the purpose. The draft of water being small, a *full* form of midship section is requisite; therefore fig. 7 will be the best form to start with. In regard to this midship section, he will observe that the corners being rounded off, the stability is therefore increased, but that it will *not* give the necessary displacement without increasing the breadth. He can therefore add a foot to the breadth of beam to make up for the roundness of the bilge. In regard to "*shoulder*," the value of that will have to be left to a later calculation, when the final beam is determined.

Before going farther, he must now pass to the character of the bow and stern of the intended ship. Table XXII., on page 160, gives the length of entrance and run required for the given speed of ten (10) *knots.* For that speed (about 12 statute miles), with the least resistance, the "*entrance*" must be 60.5 feet long and the "*run*" 43.2 feet. Adding 7 feet for the screw and appendages will give the architect a bow of 60 feet length and a run of 50; and if he does not fancy the idea of so much fineness, he may cut off ten feet from the extreme sharpness of the bow, reducing it to 50 feet entrance.

But the architect sees, at once, that in leaving the box form and adopting the "wave" form of sharp bow and fine run, he has lost carrying power and sacrificed displacement to speed; how is he to replace this lost quantity? For this purpose he must go to Chapter XXIII., Table XXII., and, by calculation, see how much capacity remains to him in the 50 feet of entrance and 43 feet of run left. He will see that only about 58 per cent. of the original displacement is left; and therefore 42 per cent. must be replaced elsewhere. As the real displacement lost amounts to above 15,700 cubic feet, and that *must* be replaced, the only way remaining to find this last is to enlarge the midship section, for the addition of 100 square feet to the midship section, when multiplied by a co-efficient of .775 of the

length given in Table XXII. (elements of "wave" form), gives the architect a figure (15,500) almost exactly the lost displacement. The elements of the vessel will then stand thus (from Table XXII.):

	Feet.		Cubic feet.
Draft of water	15		
Beam	32		
Area of ⊠ section	465	Volume of entrance	12,787.5
Length of entrance	50	" " run	13,950
" " run	50		
" " middle body	100	Volume of middle body (immersed)	46,500
			73,237.5
		Originally stated	75,000
		Deficiency	1,763

This deficiency can be made up by making the bow and stern a trifle more full.

The architect can now determine the minimum height of the out-of-water body. This must be at least 4 feet, and as he knows that the block just sketched out is more than enough to give the capacity of the original parallelogram, 3 feet by 6400, he is certain that the vessel will not only carry the weight at the speed required on the draft of water wanted, but that she will also have room to stow the cargo under hatches.

The next point is to see whether, under these circumstances, the "shoulder" obtained possesses adequate ability to carry the sail area of such a ship, supposing her to be required to be propelled at ten (10) knots in a fresh breeze by the ordinary area of sail. This question requires that he should value approximately the strength of the "shoulder." This is also done by the use of Table XXII.

Having settled that the quantity of shoulder under these dimensions will carry the required area of sail, he can next choose that form of midship section which, on the whole, he conceives to be best suited to make the vessel easy, comfortable and seaworthy in the particular service on which she is to be engaged. For this purpose it must be remembered that she may not always be deeply ladened, but may sometimes be light and in ballast. Elsewhere it has been said that

a dry and easy-going sea vessel should have a little flare out, a circular or vertical line at the water's edge; and if she were always at one draft of water, it might be easy to give a perfect construction for a single part of that draft. Remembering, however, that this vessel may go to sea light, and that her light water-line may probably be 12 feet instead of 15, the architect should construct her on a 12-feet draft with her widest part at *that* draft, and allow the "tumble-home" to commence from that point upward. This would go farthest to prevent the flare-out of any portion of the hull where such overhang would be sure to oppose resistance to the waves and cause uneasy movements.

The architect has to choose, then, a form of midship section having exactly an area of 465 square feet immersed.

The section provisionally chosen (fig. 7) is *wall-sided*, dead flat on the *floor*, and has two circular *bilges*. If the vessel is to take the ground, this form cannot be bettered; and as she is limited to draft of water, she cannot dispense with any of the fullness of this midship section; therefore the question really is, Shall the architect slightly increase the *beam* in order slightly to increase the fineness of the bottom? The answer to this is, that beyond a few inches to give curvature to the side and reconcile the round bilge to the tumble-home, the midship section in this case should not be altered, and what is thus put at the light water-line should be taken off the bilge, and no more.

But suppose that the sails are to play a more important part in this vessel, and the machinery a less important part—it may then be expedient to ask, What change should be made? The answer is, Very little, unless the draft of water can be increased; for if that *can* be done, finer bilges, or *rise of floor*, should be substituted, so as to make the bottom sharper and get more hold of water, thus preventing leewardliness. Having done this, the inquiry should be repeated, Whether, under the present beam, the vessel would have power of "shoulder" sufficient to stand up stiffly under her standard sail area?

The following is the investigation of her power of "shoulder" or stability. The volume of shoulder *approximately* at the standard inclination of 14° 2′ is 614,672 lbs., and the centre of gravity of the shoulder from the middle line would be about 9 feet. Hence the *moment* of the shoulder (see Table XXII.) is 5,532,048 feet.

This is the power of the "shoulder" to carry, and the sail area must next be considered. For that purpose turn to Chapter XIX., on sail area. There it is found that the standard sail area should be six times the longitudinal area, or 18,000 square feet; this, at 1 lb. per square foot, gives a pressure of 18,000 lbs., and as the power of the shoulder is known, the architect has the following calculation:

In Chapter XIX., Table XI., the height of the centre of effort is found to be equal to $1.412 \times a$, in which a is equal to half the *length* of the *mainyard* or the *height* of the *main-course*. To find the length of the mainyard consult Table XII. A length of 70 feet there corresponds to a sail area of 17,818 square feet, which is near enough for the purpose. Hence the height of the centre of effort is equal to $1.412 \times 35 = 49.42$ feet; this means the height above the bottom of the sail; therefore, adding about 10 feet to this to clear the bulwarks, the architect has for the height of the centre of effort above the water-line 59.42 feet. This quantity, multiplied by the *cosine* of the angle of inclination, or .9701, will give the actual leverage of the sails.

The result is, therefore, $59.42 \times .9701 = 57.63$ feet, and for the

Moment of sails................	$18,000 \times 57.63$	$= 1,037,340$
Moment of "shoulder".......		$= 5,532,048$
Difference...		4,494,708

This difference, divided by the forces which have been considered—viz., "shoulder" and sails—gives a measure of stability of 7 feet; and be it remembered that the shoulder has been taken at its minimum, because if "the lines" were got out, this power of shoulder would greatly increase in the after body; and moreover there is a parallel body of 100 feet, which also adds greatly to the power of the "shoulder." Leaving for the present the centre of gravity of the weights out of the question, there is another and greater power counteracting the power of the "shoulder"—namely, the bottom buoyancy.

The bottom buoyancy is equal to the displacement *minus* the volume of the "shoulder," or $4,612,800 - 614,672 = 3,998,128$ lbs.

The architect may presume without great inaccuracy that the centre of bottom buoyancy is situated about 8 feet below the load water-line; this, multiplied by the *sine* of the angle of inclination, or .2425, gives for

The moment of bottom buoyancy....................	7,756,368
Subtracting the difference before found...........	4,494,708
Leaves a surplus of *instability* of.....................	3,261,660

or a measure of *instability* of .7, or nearly 9 inches.

This measure is what has throughout been called "the measure of stability of form," and it will therefore be seen that if the centre of all the weights on board were to fall in the load-water line, this ship, under the above pressure, would capsize. But let the architect examine a little farther and see whether he may fairly take that centre as a rough approximation. The vessel would be at least 20 feet in depth (not *draft*); may he not then fairly suppose that the centre of concentrated weight would at its maximum height from the bottom be situated at half that depth, or ten feet? And if so, he will have a righting moment of 11,186,040 lbs., and therefore a *surplus* moment of stability of 7,924,380, or a measure of stability of nearly 2 feet, which would give a meta-centric height of 8 feet above the centre of gravity of the vessel, or a height of 11 feet above the centre of buoyancy (*i. e.*, centre of gravity of displacement), which is *more* than is necessary in such a merchant vessel.

The question of the position of the centre of weight is a practical one of *very great importance.* The commander of the ship, and not the constructor, has it in his power to shift this as he pleases: if, therefore, he stows his light goods below and his heavy goods above, and finds his ship unstable, it is his fault and *not* the constructor's; but if he stows the heavy goods below and the light ones above, so as to get the centre of gravity well down, he will find his ship stable.

He can by this calculation see that if his vessel is empty the centre of the weight will be situated above the water-line, thereby tending to capsize the ship. To know how much ballast must be put in under these circumstances, commence by supposing the vessel when light to draw 10 feet of water, the displacement will then have been decreased by 1,536,000 lbs., or the remaining part will be equal to 3,076,800 lbs.

Let it also be supposed that the volume of the "shoulder" has remained the same, which may fairly be done, having kept the greatest breadth at the light-line; there results the following:

Moment of bottom buoyancy...........................	3,274,463
" " sails..	1,037,340
	4,311,803
Moment of "shoulder"................................	5,532,048
Surplus in favor of stability.........................	1,220,245

Hence it will be seen that, with the section chosen, the vessel when light will still have stability; which may seem remarkable, but is yet a fact. But *if* she draws 12 feet of water, she will need 140 tons of lading or ballast to make her stable. It is the form of midship section which rules this; and by studying it out after the manner given in Chapter XI., fig. 5, Table VI., and Chapter XIII., figs. 7 and 15, it will clearly be seen that some forms of midship section, when light, will have very great stability; whereas when down in the water they will require ballast or bottom weight to make them stable. Under the supposition that the vessel would draw 12 feet of water, the same calculation as above would be necessary, and a difference in favor of instability would be found; this divided by the sum of the forces, and that quotient again divided by 2240, would give the quantity of tons of ballast required. By putting this ballast in, of course the vessel would sink about a foot or so deeper in the water, and thereby increase the bottom buoyancy; but, on the other hand, the centre of gravity also lowers 1 foot more, as originally supposed, and thereby neutralizes the effect of the increased bottom buoyancy. The summary is, that the ship has ample power to carry her sail, provided that, when laden, the centre of all the weights be at least 3 feet below the water-line, and that, when light, the centre of her weight be lowered by 140 tons ballast on board, in case the draft is only 12 feet of water.

The next question is the power requisite to drive her? This depends on the resistance of the shape to the water; and for the calculation of that, there is the following data: The fullness of the bow is represented by the co-efficient .25. At 10 knots, by Table XVII., page 161, the resistance is 285 lbs. to the square foot, or $\frac{285}{4} \times 465$ for the whole immersed ⊠, or 33,131.25 lbs. This in horse-power* is $\frac{8.7}{4} = 2.19$ indicated horse-power per square foot of midship section, or 1018.2 for the whole. But the ship's skin consists of nearly

* One horse-power will lift 33,000 lbs. one foot high in 1 minute of time.

60 feet periphery of middle body, by 100 feet length; and the skin of the after and fore bodies together amounts to 4368, according to the formula mentioned at the end of Chapter XXIII., Table XXII. For the skin, therefore, alone, there is required an additional horse-power of 330.6, and hence the whole horse-power required for the propulsion of the ship will be $1018.2 + 330.6 = 1348.8$ indicated horse-power. The next question is, Can such a ship be propelled by engines and boilers weighing not more than 150 tons, at the speed required by the owner? If the engines are 180 nominal horse-power,* they may be assumed able to work up to six times this power, or 1080 indicated horse-power; and it is plain, then, that these engines cannot drive the ship when laden at *ten* knots the hour, but only at *nine* knots; though when she is light, or at 12 feet draft, they will drive her at greater speed. But the architect has still to provide for the loss by the screw and slip, as well as the percentage of working power consumed by the engines themselves, and these will require an addition, say, of *one-fifth* to the engine power. Making that allowance, there results for the power required to drive the vessel at the given speed—

Loaded............................	1618.6 indicated horse-power.
Light..............................	1296. " "

It is quite plain that the conditions required by the owner are *not* fulfilled, and the question may be asked, Will he prefer to take her as she is, relying on the sails to supply the deficient power, or will he insist on the speed required at the outset? If he is content with her as she is, all that the designer will have to do is to frame the best design he can to combine the working of the steam and sails together. But if not, the architect must go to a larger size of ship; in short, he must *lengthen* the ship.

Suppose, then, that he proceeds to do this, so as to make the vessel completely fulfill the intentions of the owner. This may be called the revised or corrected design.

The only means he has now of increasing the speed without in-

* The nominal horse-power of a vessel is obtained by the formula—

$$\text{H P} = \frac{\text{Area of cylinder} \times \text{effective pressure} \times \text{speed of piston.}}{33{,}000}$$

The effective pressure being taken at from 7 to $7\frac{1}{2}$ lbs. per square inch, and the speed of the piston being assumed arbitrarily according to the length of stroke.

creasing the area of midship section is to add to the length of the entrance. To a speed of 10 knots, or 11.52 statute miles, per hour belongs an entrance of about 60 feet. Add then to that 20 feet, and shorten the parallel body to 90 feet, which will make the whole length of entrance, which was theoretically 60 and practically 50, now theoretically 90 and practically 80, and yet the same displacement nearly as before—viz., 2120 tons—is retained; but it will also be found that the resistance due to this displacement is reduced from $\frac{32}{60}$ to $\frac{32}{90}$ (Table XIX.), or nearly one-third. Instead, therefore, of requiring 1018 horse-power to do 10 knots an hour, there is now required only 515 horse-power. Adding to this the additional skin resistance of 18.2 (besides 330.6) there is now a total required horse-power of 864 (indicated), and adding to this one-fifth for use of engine and propeller, etc., 1037 horse-power; so that now the vessel can comfortably perform under her engines the speed required. Of course the ship is more expensive to build, and the hull will weigh a little more; but if speed be of great value to the owner, the extra cost will be in the end profitable.

The final dimensions of the ship now are—length, 220 feet; breadth, 32 feet; depth, 20 feet.

There are two calculations yet unperformed. One is, How much fuel the vessel will consume, and whether the quantity of coal which has been assumed to do the required work will really perform it in ordinary states of the weather and sea?

The other point which remains unsolved is the position of all the weights in the ship, and their action on the balance and trim of the ship; whether these be weights of engines, of boilers, of equipment, of fuel, of cargo, or of ballast, in both conditions of heavy lading and extreme light draft.

These are points on which, at this stage of the matter, the naval architect can have no accurate knowledge; he must go into the second part of the work and ascertain what is the dead weight of the hull of the ship, and how on that hull the weight of iron or of wood is distributed; whether bow and stern are equally heavy or proportioned in weight to their respective displacements; so that the centre of gravity is either in the middle or out of the middle of the ship. This found, he must then take care to place the weight of the engines and boilers so far abaft the middle that the ship when light

shall be well down abaft, instead of by the head; and he may then so distribute the stock of fuel that when full of coal the ship shall be working on an even keel, and not draw more than the 15 feet of water which is her limit; so that as she lightens of coal she shall gradually rise higher out of the water at the bow than at the stern; in order that when all the fuel has gone she may still be in good sailing or working trim. But for this he must go into the subject of *practical construction* and practical disposition of materials in the ship.

The length of keel for tonnage being equal to $220 - \left(\frac{3 \times 32}{5}\right) =$ 200.8 feet; hence the tonnage by B. M. $= 200.8 \times 32 \times 16 \div 94 =$ 1093.7 tons.

The vessel has an actual middle body of 80 feet.

Treating this part by itself as regards capacity, and acting with the remaining 140 feet as would be done with a ship without any middle body, there results—

	Tons.
For the external capacity $= 140 \times 32 \times 20 \times 0.7 \div 100 =$	627.2
" " of middle body $= 625 \times 80 \div 100$....... $=$	500
Total....................................	1127.2

For the gross internal capacity the constructor has 90,000 cubic feet, or 900 tons, according to Chapter V., p. 34. From this he must deduct about 20 per cent. for equipment, etc., to get the cargo space equal to 72,000 cubic feet. Further, the space occupied between the engine-room bulkheads is, let it be supposed, 40 feet; mean breadth, say 28 feet, including coal-bunkers; and the mean depth 18 feet. The capacity of the engine-room is then $= 40 \times 28 \times 18 = 20{,}160$ cubic feet, or 201.6 tons; the register tonnage, therefore, would be equal to $72{,}000 - 20{,}160 = 51{,}840 = 518.4$ tons, the ton taken at 100 cubic feet. This, taken at 50 cubic feet per ton, would give the quantity of cargo which could be carried, 1036.8. It is further to be observed that the vessel must carry fuel for at least 8 days, her supply being reckoned at 1.5 cwt. per mile, and her speed to be 10 knots, or 11.52 statute miles per hour. The quantity of coal she must carry will therefore be equal to $0.075 \times 11.52 \times 24 \times 8 = 165.89$ tons, and this is more than is generally allowed. Taking the average consumption of bituminous coals of 48 vessels, whose *nominal* horse-power varies from 100 to 450, it is found to be 10.5 lbs. per nominal horse-

power per hour. This would give, for eight days, 135 tons. Ample allowance has therefore been made.

These 165 tons must be stowed in side-bunkers, and therefore do not take away from the cargo space.

The constructor has, therefore, the following summary:

Length of ship	220 feet.
Length of keel for tonnage	220.8 "
Breadth extreme	32 "
Depth at the side	20 "
Draft of water	15 "
Tonnage, builder's measurement	1093.7 tons.*
Gross register tonnage (100 cubic feet to 1 ton).	900 "
Tonnage of engine-room (length 40 feet)	201.6 "
Net register tonnage	698.4 "
Area of immersed midship section	465 sq. feet.
Area of midship section up to deck	625 "

Weights.

	Tons.	
Ship's hull	437.48	= 0.4 × builder's tonnage.
Masts, spars, anchors, boats, etc.	109.37	= 0.1 × "
Engines and boilers	150	
Cargo	1036	= 50 cubic feet per ton.
Coals	165	= 48 " "
Equipment and sea stores	150	
Provisions and water	50	
Total	2097.85	
Displacement	2120	(35 cubic feet to 1 ton).

* The formula for builder's measurement is—

$$T = \frac{bd}{94}(l - \tfrac{3}{5}b) \text{ where}$$

l is the length from fore part of *stem* to after part of *post;*

b the extreme breadth above *main-wales;*

d the depth, which, for double-decked vessels, equals half the beam.

CHAPTER XXX.

HOW TO SET ABOUT THE DESIGN OF A MAN-OF-WAR.

When a merchant ship is spoken of, it is usual to say a vessel of so many tons, indicating the vessel's capacity and the weight she can carry; but when a man-of-war is spoken of, it is usual to designate her by the number of guns she carries—meaning, of course, her weight of metal.

A naval architect may be able to design a merchant vessel to perfection, and yet be totally unable to design a man-of-war. Especially with the modern ships is this a task most difficult; they carry a quantity of heavy iron plates in such a position that, when no especial care is bestowed upon the design, the vessel must prove a perfect failure. In a merchant vessel the weights are carried below, while in a man-of-war they are nearly all carried above the water-line.

Suppose a man-of-war is to be designed (see Chap. V., p. 35) to carry 50 guns, and of these, 36 upon the main deck and 14 on the spar deck, the latter being distributed on the forecastle and quarter deck, while the main-deck guns are distributed 18 in each broadside. It is the length of the ship that is mainly affected by the 36 broadside guns. Experience has proved that the lower portsill must be at least 9 feet out of the water; but in some vessels that height has been increased to 10 and even to 11 feet. Suppose the height determined to be 10 feet 6 inches, the ports to be 3 feet high, and a space of 2 feet kept above the upper portsill, then the constructor has already a height out of water of 10.5 feet $+ 3 + 2 = 15$ feet 6 inches.

This will be the height out of water of the top of the beam of the upper deck at the side of the ship. He has, therefore, already made

a side wall for the vessel's battery of say 16 feet out of water. Now, what should the *length* of this side wall be? In former days the space between the guns was seldom more than 8 feet. The distance now-a-days, on account of lateral train, is extended to 15 and even 18 feet;* but assume 15 feet as a distance from centre to centre. The constructor has therefore, for the length to be occupied by his battery, $18 \times 15 = 270$ feet.

Suppose, further, that the speed of the vessel is to be 13 *knots*. To this speed belongs a length of ship of 161 feet, or a length of *entrance* of 94 feet, and a length of *run* of 67 feet.† Make the length of the ship, then, say 300 feet,‡ and assume the beam to be 52 feet, or a proportion of 6 to 1. The constructor has then the following preliminary dimensions:

Length..300 feet.
Breadth..52 "
Height of lower portsill above load water-line, 10 feet 6 inches.

Next comes the element of draft. A man-of-war must always be supposed in a loaded condition, or down to her load water-line, that water-line being the one on which she has got to do the work. The light water-line may, therefore, be left out of the question. Now, if this man-of-war were to be of box form or of rectangular shape, with square bilges, Table V. would give the critical proportions of draft to breadth, for by that table it is seen that to a beam of 54 feet belongs a critical draft of 22 feet, and that such a form would not be able to carry top weight. The adopted beam is, however, 52 feet, and therefore the constructor may safely assume a draft of 22 feet, especially as he intends probably to give *rise of floor* to the midship section. Suppose, further, that the co-efficient of fineness of the midship section is 0.8; the area of the midship section will then be $22 \times 52 \times .8 = 915.2$ square feet. Now is the time for the designer to see in how far he can adopt fine lines and still have displacement enough to carry the weight required.

For a speed of 13 knots it was seen that a length of entrance and run was needed of 161 feet, which, subtracted from 300 feet, leaves

* For XI-inch gun on iron carriage, 18 feet.

† Supposing that she is designed according to the "Wave" system. (See Table XVI., p. 160.)

‡ By the addition of middle body.

a length of middle body of 139 feet. Hence the constructor has for the displacement (Table XXII.)—

	Cubic feet.
Middle body	127,212.8
The ends	87,840.0
Total	215,052.8

But the constructor needs 6300 × 35 = 220,500 cubic feet. He has, therefore, 220,500 — 215,052.8 = 5447.2 cubic feet, or 155.6 tons too little.

To make this up, the midship section may be made fuller without damage—say 950 square feet nearly. The displacement is thus increased to 224,000 cubic feet—more than enough; and then, taking the fraction of 0.6 for the fineness of the ends, the constructor has the following:

	Feet.
Length on load water-line	300
" of entrance	94
" of run	67
" of straight middle body	139
Beam	52
Draft of water	22
Depth at the side	42

Area of immersed midship section = 22 × 52 × .83 = 949.52 square feet.

Displacement of middle body, 131,983 cubic feet, or 3771 tons.

Displacement of fore and after bodies together, 91,770 cubic feet, or 2622 tons, or—

	Cubic feet.	Tons.
	131,983.	= 3771
	91,770	= 2622
Total	223,753	= 6393
Required	220,500	= 6300
Surplus	3,253	= 93

This surplus might easily be rectified by making the lines finer, or, in other words, by taking a little away from the middle body and making longer ends. But the constructor may be satisfied that, with the given dimensions and proportions, the ship will carry her weights.

Now comes the question of stability, for which (see Table XXII.) he obtains the following:

Volume of shoulder of the ends $= 0.1875 \times b \times L \times c + 0.3927 \times b^2 \times c$, wherein $b = 26$, $L = 161$, and $c = 13$; hence—

Volume of shoulder of the ends $= 0.1875 \times 26 \times 161 \times 13 + 0.3927 \times 676 \times 13$, or $= 10203.375 + 3451.0476 = 13{,}654.4226$ cubic feet.

Volume of shoulder for middle body $= 26 \times 6.5 \times 139 = 23{,}491$ cubic feet.

Volume of whole shoulder $= 13{,}654.4226 + 23{,}491 = 37{,}145.4226$ cubic feet.

Or, in lbs., the volume of shoulder is $= 37{,}145.4226 \times 64 = 2{,}377{,}307.0464$.

Volume of bottom buoyancy $= 223{,}753 - 37{,}145.4226 = 186{,}607.5774$ cubic feet.

Volume of bottom buoyancy in lbs. $= 186{,}607.5774 \times 64 = 11{,}942{,}884.9536$.

Centre of gravity of shoulder from middle (ends) $= .56 \times b$.

Centre of gravity of shoulder from middle (middle body) $= .666 \times b = \frac{2}{3} b$.

Moment of shoulder of the ends $= 13{,}654.4226 \times 14.56 = 198{,}808.393056$ cubic feet $\times 64$.

Or, in foot lbs. $= 12{,}723{,}737.155584$.

Moment of shoulder of the middle body $= 23{,}491 \times 17.33 = 407{,}099.03$.

Or, in foot lbs., 26,054,337.92; hence—

Moment of whole shoulder $= 38{,}778{,}075.075584$ foot lbs.

Moment of bottom buoyancy $= 11{,}942{,}884.9536 \times 11 \times .2425 = 31{,}857{,}645.6137$ foot lbs.

Moment of stability of form $= 6{,}920{,}429.4618$ foot lbs.

Measure of stability of form $= 0.4832$ feet.

And we have therefore—

Height of the meta-centre above load-water line $= \dfrac{.4832}{.2425} = 1.992$ feet.

Taking approximately the centre of displacement as 10 feet below the load water-line, the interval of 11.992, or nearly 12 feet, is obtained. This may seem small, but it must be considered that the power of the shoulder is taken at its minimum, and, in reality, may

be increased from 25 to 50 per cent., while the bottom buoyancy is maintained.

The next point is to see the effect the *weights* will have.

The guns are to weigh, say, 500 tons, and the centre of gravity of this weight is to be, say, 13.5 feet above the load water-line. The centre of gravity of the hull alone may be supposed to be in the load water-line, which should be the case in men-of-war, their hulls generally being as much out of water as in it. Further, suppose the centre of weight of the engines, boilers, coals, etc., to be situated at half the draft, or 11 feet below the water-line. To find, therefore, the common centre of gravity, or the centre of all the weights, the

		Foot tons.
Moment of guns.....................	$= 500 \times 13.5 =$	6750
" of masts, spars, etc.......	$= 155 \times 80 =$	12,400

Considering these moments as negative, their sum is 19,150 foot tons; then—

		Foot tons.
Moment of hull.......................	$= 3000 \times 0$	
" of engines, boilers, etc....	$= 1000 \times 11 =$	11,000
" of coals.....................	$= 1000 \times 11 =$	11,000
" of sundries..................	$= 738 \times 10 =$	7,380

Considering these last as positive, their sum is 29,380; deducting from this the negative moments, there remains $29,380 - 19,150 = 10,230$ foot tons, and this divided by the sum of all the weights gives the place of the common centre of gravity as $\frac{10,230}{6393} = 1.6$ feet below the load water-line.

The distance of the centre of all the weights from the meta-centre will, therefore, be equal to $1.992 + 1.6 = 3.592$ feet. The moment of stability with weight, at an angle of 14° 2′, is therefore $3.592 \times 6393 \times 0.2425$, or 5568.4 foot tons.

The next point is to determine the sail area. In merchant ships six times the longitudinal area is taken; in sailing yachts, six to twelve times that area; but in men-of-war, from six to four times the area is usual—the old frigates having, generally, but four times the area of immersed longitudinal section.

Assume the sail area to be five times the longitudinal area, or $5 \times 300 \times 22 = 33,000$ square feet of canvas, or taking the proportion of 36 square feet of canvas to every square foot of midship section,

the sail area would be 34,182 square feet; and this larger quantity is better, and will give a length of main-yard of about 96 feet—hence 88 feet is the height of the centre of effort above the water-line.

Supposing the pressure on the sails to be equal to 1 lb. to the square foot, it results that there is 34,182 lbs. acting with a leverage of 88 square feet; but since the vessel has careened 14° 2′, the cosine of this angle must be introduced as a factor. This gives 1291.26 foot tons as the upsetting moment due to the sails. Now the moment of stability with weight being 5568.4 foot tons, it is seen that there is surplus stability sufficient to bear a pressure of $4\frac{1}{2}$ lbs. instead of 1 lb. on each foot of standard sail area; which is a margin more than sufficient.

The sail area, therefore, might be, if necessary, much increased, the ship having ample stability.

The next question is, whether the engines will drive the ship 13 knots per hour? For this purpose the constructor must see what head resistance is to be overcome.

By Table XVII. it will be seen that to a speed of 13 knots belongs a head resistance of 482 lbs. to every square foot of midship section. The length of bow gives for a diminished fraction $\frac{52}{94} = .306$. The constructor, therefore, has for head resistance $949.52 \times .306 \times 482 = 140,046$ lbs.

Horse-power necessary to overcome the above, equal to $19.2 \times .306 \times 949.52 = 5578.62$ *indicated* horse-power.

For the *wet surface*, the following is a near approximation:

Periphery of midship section...		80 feet.
Skin of middle body.............	80 × 139.0	= 11,120 square feet.
Skin of fore and after bodies...	80 × 161 × .5	= 6,440 " "
Total.................		= 17,560 " "

or, at 1 lb., equal to 17,560 lbs.

Horse-power necessary to overcome the last-named element of resistance is

$\frac{17,560}{482} \times 19.25 = 701.28$ *indicated* horse-power. The total power required is, therefore, $5578.62 + 701.28 = 6279.90$.

Supposing the engines to have worked up to five times their *nomi-*

nal power, this nominal power would be equal to 1255.98 horse-power; and to this must be added one-fifth for *slip, and the power consumed by the engines themselves,* and the constructor finally gets for the power required to do the work, 1507.17 nominal, or 7535.85 indicated horse-power.

Hence there is for the man-of-war in question the following principal dimensions:

Length on load water-line	300	feet.
" of entrance	94	"
" of run	67	"
" of middle body	139	"
Breadth, extreme	52	"
Depth at side	42	"
Draft of water	22	"
Tonnage, builder's	3866	tons.
Displacement	6393	"
Speed, in knots	13	
Area of immersed midship section	949	sq. ft.
Distance between the ports	15	feet.
Height of lower port-sill above load water-line	10	ft. 6 in.
Number of guns	50	
Indicated horse-power required	7535.85	

From which data, taken in connection with that on page 35, the drawings may be made.

CHAPTER XXXI.

PRACTICAL METHOD OF ASCERTAINING THE CENTRE OF GRAVITY OF A MAN-OF-WAR, WITH ALL HER WEIGHTS ON BOARD AND READY FOR SEA.

Any commander of a vessel possessed of a fair amount of mathematical knowledge, and having the *drawings* of his ship, can ascertain for himself the position of the centre of gravity in a very short time. The knowledge of this position is matter of very great importance.

The following is a rationale of the process:

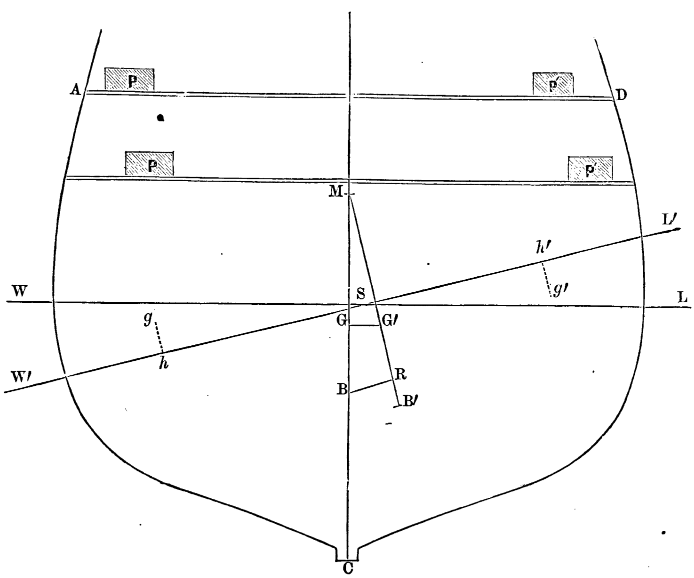


Fig. 44.

Let ACD (fig. 44) represent the transverse section of a ship through G, the common centre of gravity of the hull and every article on

board; WL the load water-line when the ship is floating in the upright position; CBGM the middle line, which is therefore perpendicular to WL, and also contains G the centre of gravity of the ship; and B the centre of buoyancy (or centre of gravity of displacement); let, also, P represent a weight or weights on any or all of the decks, such as guns, shot, ballast, etc., capable of being readily transported to the opposite side of the deck or decks. If the weight or weights P be moved across the decks to P′, the ship will incline through an angle WSW′, the amplitude of which will depend, *cœteris paribus,* upon the weight or weights moved, and the distance through which they have been moved.

When the ship has taken up the new position of equilibrium, the centre of buoyancy will have moved from B to B′, and the centre of gravity from G to G′; so that the line joining B′ and G′ will be vertical, and therefore perpendicular to W′L′ the new water-line, and will make the same angle BMB′ with the middle line BGM as the water-lines do with each other, and B′G′ produced will meet the middle line in a point M. This point, in ships of the usual form, may, without any appreciable error, be assumed to coincide with the *meta-centre* when the inclination *does not exceed* 4° or 5°.

From a general and well-known property of the centre of gravity of a system of bodies, such as a ship, we know that since the weight or weights P have been moved in a horizontal direction to P′, the centre of gravity has also moved in the same direction; therefore GG′, the line joining the original, and the new centres of gravity, will be horizontal; and from another property of the centre of gravity we have that the weight of the ship × GG′ = P × the distance through which it has been moved; or, if W represent the total weight of the ship, and c the distance through which the centre of gravity of the weight or weights P has been moved,

$$W \times GG' = P\,c$$

and

$$GG' = \frac{Pc}{W}$$

Now by trigonometry GG′ = GM × tangent of the angle between the middle line BGM and the new vertical line B′G′M; *i. e.*, the angle of the ship's inclination from the upright; or representing the angle of inclination by θ,

$$GG' = GM \tan \theta$$

Equating the two values of GG′ thus obtained,

$$\frac{Pc}{W} = GM \tan\theta$$

or

$$GM = \frac{Pc}{W} \div \tan\theta \qquad (1)$$

The right-hand member of this equation (1) will contain all known quantities after the ship has been inclined; and since the *meta-centre* corresponding to any draft of water is easily obtained by calculation from the drawings of the ship, and its position fixed, the distance GM set off *below* it will give the position of the centre of gravity of the ship.

Should the inclination obtained by the movement of the weights on board be greater than 4° or 5°, the vertical through the new centre of buoyancy *may not* pass through the *meta-centre*, but through another point of the middle line, found in the following manner:

Through B draw BR parallel to W′L′, and therefore perpendicular to B′G′. Let A represent the weight of the water displaced by either of the equal wedges WSW′, LSL′ of which the centres of gravity are g and g' respectively. From g and g' let fall the perpendiculars gh and $g'h'$ upon W′L′, and let b represent the distance hh'. The product bA may be found by the ordinary methods of calculation, and is, in fact, the first part of the expression representing the moment of stability of the ship.

Now, by the general property of the centre of gravity before made use of, since the wedge WSW′ concentrated in g, its centre of gravity, has been moved in the direction W′L′, through a distance b to LSL′ concentrated in g', the distance BR through which the centre of buoyancy has moved in the same direction is equal to $\frac{bA}{W}$

But by trigonometry

$$\begin{aligned} BR &= BM \sin\theta \\ &= GM \sin\theta + BG \sin\theta \end{aligned}$$

Again,

$$GM \sin\theta = \frac{GG'}{\tan\theta} \sin\theta = GG' \cos\theta = \frac{Pc}{W} \cos\theta$$

$$\therefore \frac{bA}{W} = \frac{Pc}{W} \cos\theta + BG \sin\theta$$

and

$$BG = \frac{bA - Pc\cos\theta}{W \sin\theta} \qquad (2)$$

The right-hand side of this equation (2) contains all known quantities after the experiments have been made, and the distance BG thus found, set off *above* the centre of buoyancy B, will determine the position of the centre of gravity of the ship. In equations (1) and (2), since W represents the displacement of the ship, calculated to the draft of water taken at the time of the experiment, the greatest possible care should be taken to obtain the correct draft of water, and also to obtain a close approximation to the cubic contents of the part of the ship immersed; any errors made in either will affect the assigned position of the centre of gravity. The same care should also be taken to obtain the correct positions of the centre of buoyancy and the *meta-centre*, since these points are taken as origins from which the distances to the centre of gravity, as above, are set off.

Again: P being the sum of all the weights moved, and which alone is assumed to have caused the inclination, all weights moved should be accurately known, and also the distance c measured transversely, through which the centre of gravity of the same has moved in a horizontal direction; and every precaution should be taken to prevent the motion of any article which cannot be thus estimated. The ship should, therefore, be pumped out dry, coal and such articles prevented from shifting, and at the several times of making the observations *every man* on board should be in a given position. Finally, the angle of inclination (θ) is found with the greatest exactness in the following manner:

A thick board, above 20 feet long, is nailed to the coamings of the main hatchway in a vertical direction when the ship is upright; and on its lower end a straight batten is nailed at right angles to the board, or horizontally from the upper part of the batten. A distance of 20 feet is carefully set off upward, and at the height thus obtained a nail is driven into the board, and to it is attached a plumb-line, the plummet hanging freely at some distance below the batten. When the vessel is upright, and the experiment about to be commenced, the point where the plumb-line intersects the upper edge of the batten is carefully marked; and when the ship has attained her new position of equilibrium by the movement of the weights, the new point of intersection of the plumb-line and the upper edge of the batten is marked in like manner; the distance in feet between the two points marked on the batten, divided by 20, will clearly give

the tangent of the angle of the ship's inclination. In all the experiments made in accordance with the foregoing there were two (2) plumb-boards nailed to the hatchway—one amidships, and the other about midway between it and one of the extremities of the ship. The two boards, being independent of each other, were intended to serve as mutual checks, and also to point out any rocking of the ship which might be occasioned by the movement of the weights on board. It was observed that the plummet was nearly always in a state of vibration, and therefore it was considered best to observe the extreme positions of the plumb-line on the upper edge of the batten and obtain the mean position from them.

The following is an account of the experiment, as tried at Plymouth upon the English screw ship-of-the-line "Conqueror." On the day of the experiment it was smooth, with very little wind, thus affording an opportunity of recording the draft, *forward* and *aft*, accurately. The vessel was completely fitted and rigged, the two bower anchors were down, and the guns run out. She had on board 508 men, with provisions for three months; 60 tons of water in the tanks; 517 tons of coal in the bunkers, and *two* of the boilers were filled.

After the usual preparations had been made, such as fixing the two plumb-boards, marking the positions of the gun-trucks on the deck, and pumping the ship out, the men were ordered to take up positions at ease, one-half on each side of the deck, and each man to note his position for himself, so as to take it again if ordered. The draft of water was also accurately taken.

When all was quiet and the ship steady, the points in which the plumb-lines crossed the upper edges of the cross battens were carefully marked, as already described—an operation scarcely occupying half a minute, and it is only during this process that the men need be under any constraint.

The men were then ordered to run the guns of *all* the decks over on one side of the ship as far as practicable, and nearly opposite their respective ports, with the axes of the guns in the same direction as they were before, so as to simplify the calculations as much as possible. As the guns were removed, the same part of the trucks was again marked on the deck; and after all the guns were over the men were ordered to resume their stations as before directed. When all

was quiet, the points in which the plumb-lines crossed the upper edges of the cross battens were marked *at the same time;* and the deflection of the plumb-line read off from both boards was found to be $12\frac{1}{4}$ inches. The guns were then replaced, the other battery moved across, and the plumb-boards showed for the second experiment a deflection from the upright in 20 feet of $15\frac{3}{8}$ inches, corresponding to an inclination of about $3° 40'$.

The work of the crew here terminated, two registered inclinations having been obtained.

An account of the weights moved and the *distance* through which *each* was moved was next taken. The weight of the guns was of course marked on them, and the weight of the carriage, etc., was also noted down. This was most carefully done.

Of course the full co-operation of all on board was absolutely necessary to make the experiment truthful.

The recorded draft of water at the time was—forward, 23 feet 10 inches; abaft, 26 feet 5 inches.

Displacement to the above line in tons, 5610.

Meta-centre above the water-line, 4.229 feet.

Meta-centre above the *lower* edge of keel, 29.354 feet.

The sum of the products of each weight, and the distance through which it was moved in the *first* experiment, was (in tons and feet) 1288.0595; and the deflection of the plumb-line from the upright in 20 feet was $12\frac{1}{4}$ inches; therefore,

$$GM = \frac{GG'}{\tan \theta} = \frac{1288.0595}{5610} \div \frac{49}{4 \times 12 \times 20} = 4.4983 \text{ feet.}$$

By the second experiment GM was found to be equal to 4.4083 feet. Taking the mean of the two experiments, the centre of gravity of the ship at the time of the experiment was 4.45 feet below the meta-centre, or 24.904 feet above the lower edge of the keel, and $2\frac{5}{8}$ inches below the corresponding water-line.

The "Conqueror," when *completely* equipped for sea, had on board 167 tons more than has been already mentioned in the foregoing account; and by making the necessary calculations consequent on the introduction of this *known* weight (ship drawing 24 feet 5 inches forward; 26 feet 10 inches aft, with all the boilers filled), the centre of gravity was found to have *fallen* through a distance of .177 feet.

The centre of gravity of the ship, then, when *fully* equipped for sea, was 24.727 above the lower edge of the keel. The corresponding *meta-centre* above the lower edge of the keel, 29.3167 feet. Consequently the meta-centre of the ship, when fully equipped for sea, was 4.5897 feet above the centre of gravity; and the centre of gravity is 25.625 feet — 24.727 feet = 0.898 feet, or $10\frac{3}{4}$ inches below the water-line.

CHAPTER XXXII.

STOWAGE AND TRIM.

SCIENCE may be exhausted in designing the immersed portion of a ship, and yet from a bad arrangement of the disposable weights, or from the introduction of unnecessary weights into the construction, or from an ill-judged leaving out of that which, to some, may appear useless or injurious, though a main part of the design, the whole may fail of a successful result.

The subject of stowage as connected with naval construction has been much neglected and much misunderstood; many persons seeming to consider that the principle of the common balance or lever governs the regulation of the weights.

At the threshold of an inquiry into the practice of stowage, one will meet with the most opposite statements, officers of equal judgment stating what they call facts, yet seemingly irreconcilable with each other, and therefore with truth; one officer stating, and truly, that his vessel pitched, and that he trimmed her by the stern, but that she pitched worse than before; another, that his ship pitched and he trimmed her by the stern and she was much improved by it; the difference not being in the facts, but in the mode of correcting the evil.

In apparent opposition to this, it has been found that a ship may 'scend though the greater weight be forward;

That a ship may miss stays uniformly, or be very long in stays, though a short ship, and this though she may be in the same trim, as regards difference of draft forward and aft, as she was when she stayed better;

A ship may not pay off in answer to her helm, though sitting by the stern; or

She may sail very well on one cruise, and very badly the next, and yet each time have the same line of flotation; or a notoriously easy ship may be made uneasy.

Now, a ship may be made to sail nearly equally well in different trims, or similar ships in different trims; and yet in none of the foregoing cases is *form* necessarily the cause of the defective or different performance, for all may be the result of a peculiar disposition of the weights. For it is quite possible by a suitable arrangement of the weights in each case, *still preserving the same line of flotation,* to make a ship stay or wear badly (despite every care in working her), to make a ship carry weather or lee helm, be easy or uneasy, steer ill or well; and even a short ship may be made to take longer in stays than a long ship.

The explanation of all this is easy upon mechanical principles, since a ship is under all circumstances a *false balance;* and this in a great degree because of the situation of the bowsprit projecting out at one extremity without a corresponding weight at an equal distance at the opposite side of the axis or point of suspension. While remaining at rest, a greater weight at a less distance will balance a less weight at greater distance, but when set in motion the balance no longer obtains, for the weights under this latter circumstance act according to the *squares* of their respective distances from the axis.

This principle was applied by Bernouilli and Chapman, though in a limited way, and in 1833 Henwood proposed that the principle should be applied not only to the stowage of ships, but also in the designing. Why that portion of it which is applicable to all vessels has not been adopted is difficult to say, unless, indeed, it be that it has not been understood.

It was formerly imagined that all necessary conditions of trim were fulfilled if the vessel were brought to a certain line of flotation, and if on the stowage being completed, she was found not at that line, 2 or 10 tons (more or less) were shifted 50 feet, or 50 tons were shifted 2 or 10 feet, indifferently (the effect on the line of flotation being the same), without supposing the effect on the ship's motions to be different; whereas the effect on the pitching motion in the one case was 25 times as much as the effect on the same motion in the other. As an example, when the English frigate "Portland" was about to sail with the "Vernon," it was found that she was not, by a consider-

able quantity, in the same trim as a sister ship (the "Winchester"), and time not permitting her to be properly trimmed, 6 tons of ballast were hastily shifted from about 30 feet abaft the centre of gravity, to 20 feet before the centre of gravity, the effect of which was—

On the Trim.	On the pitching to increase it.
$50 \times 6 = 300$	$30^2 \times 6 = 5400$
	$20^2 \times 6 = 2400$
Total............................	$= 7800$

Now had this been effected by shifting 60 tons 6 feet forward, and then $1\frac{1}{2}$ tons 39 feet aft, the trim would have been obtained and the pitching tendency not increased, since the effect would have been—

On the Trim.	On the pitching motion.
$60 \times 6 \;= 360$ forward.	$6^2 \times 60 \;= 2160$
$39 \times 1\frac{1}{2} = \;58.5$ aft.	$39^2 \times \;1\frac{1}{2} = 2135$
Requisite quantity 301.5	Practically nothing 25

The following diagram will illustrate this more fully. Let W (fig. 45) balance W′ on the lever *ab*, F being the fulcrum or centre of rotation. The moment $W \times Fa = W' \times Fb$. Now suppose the lever to make one complete revolution, then the velocity of W : velocity of W′ : : circle *ac* : circle *bd* : : $Fa : Fb$. The moment $(W \times Fa)$ $\times$ velocity of W $=$ effect of W in motion: and the moment $(W' \times Fb) \times$ velocity of W′ $=$ the effect of W′ in motion, or the momentum of $W = W \times Fa^2$ and the momentum of $W' = W' \times Fb^2$. Hence it appears that the effect of any rotary weight is as its *moment* multiplied by its *velocity*.

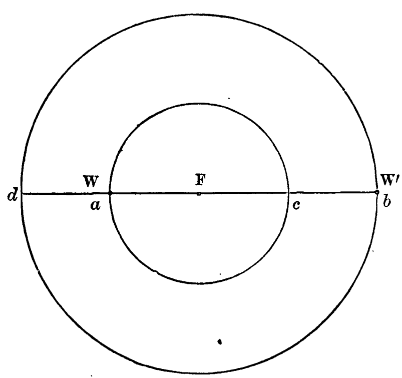


FIG. 45.

Suppose W placed at *c*, and

Let $W = 14$, $Fc = 2$, $W' = 7$, $Fb = 4$.

Moment of $W = 14 \times 2 =$ Moment $W' = 7 \times 4$.

Moment of inertia $W \;= 14 \times 2 \times 2 = \;56$.

Moment of inertia $W' = \;7 \times 4 \times 4 = 112$.

This is strictly the case of a ship if the weights be in the inverse ratio of their distances from the centre of gravity, or centre of gravity of displacement (they being both in the same vertical plane). They will balance, and therefore a ship may be brought to a given line of flotation by an *infinite* number of arrangements of the weights, but when in motion *all* differing in their effects. The consequence of this is, that similar ships may sail about equally well at different drafts or very unequally at the same draft.

It is not an uncommon practice for weights to be shifted in order to trim when sailing or chasing, or with a view to correct the defect of depression of the bow by the press of sail, from an idea of keeping the vessel at a line of flotation which will present the least area of midship section; this, however, is generally a very secondary consideration; for though it be true (all other things being equal) that the smaller the area of midship section the better, yet any good that might arise from its being small will be overborne by a bad arrangement of the weights, and a bad arrangement of weight is almost certain to be arrived at by such trimming, as a few out of numberless arrangements will suffice to show.

Suppose a vessel of 1000 tons displacement 150 feet long; the weight of the hull 500 tons; its centre of gravity at the middle of the length; the common centre of gravity to be 2 feet before that, and the bowsprit, etc., to be 8 tons, 83 feet before the common centre of gravity. Furthermore, that she is balanced by the remaining weights, as follows: 50 tons situated in the same perpendicular plane as the centre of gravity of the hull.*

Moments aft......................	$182 \times 38 \quad + \quad 2 \times 550$	$= 8{,}016$
" Forward*............	$260 \times 28.4 + 83 \times 8$	$= 8{,}048$
Moments of inertia aft.........	$182 \times 38^2 \quad + \quad 2^2 \times 550$	$= 265{,}008$
" " forward...	$260 \times 28.4^2 + 83^2 \times 8$	$= 264{,}817$
Slightly greater aft..		191

Now suppose the vessel much pressed, and 12½ tons to be shifted 40 feet aft from the centre of gravity of the fore body, then the moments of inertia would be—

* These weights and distances are quite arbitrary, yet they will as well illustrate the argument as if they were assumed from the actual design of a vessel.

Aft	= 266,690
Forward	= 254,736
	11,954

Excess aft, so that she will 'scend badly and be more leewardly, though she may steer easier.

If 50 tons could be shifted 20 feet aft from the same place, and 100 tons 5 feet forward from the centre of gravity of the after body, then the moments of inertia would be—

Aft	= 229,508
Forward	= 228,017
	1,491 aft,

or the balance would be more nearly preserved and the ship might sail and steer better for the change.

If 25 tons were shifted 20 feet aft from the centre of gravity of the after body, the moments of inertia would then be—

Aft	= 313,008
Forward	= 264,817
	48,191

or such an excess aft as would cause the ship to 'scend and pitch to a frightful extent. And if 12½ tons were shifted aft 40 feet from the centre of gravity of the hull, the moments of inertia would be—

Aft	= 287,008
Forward	= 264,817
	22,191

So great an excess aft that she would 'scend and pitch to an enormous degree.

Now, though these effects in all four cases are *so* different, yet the effect on the trim (as regards difference of draft) is the same. Lastly, suppose 5 tons to be shifted 40 feet aft from the centre of gravity of the hull, which is in the middle of the length, then the moments of inertia will be—

Aft	= 273,808
Forward	= 264,117
	8,991 excess aft.

Consequently the vessel will have a tendency to 'scend, which will increase the longitudinal oscillations and lessen the speed.

From the foregoing it will be seen how necessary it is that the naval officer should understand the principles which govern the shifting of weights when altering stowage.

Ship-Building.

Ship-Building.

CHAPTER I.

ON THE NATURE OF THE WORK TO BE DONE BY THE SHIP-BUILDER.

The work of the ship-builder is parted from that of the naval architect by the same broad line which separates the profession of the civil architect from that of the mere house-builder. In France, especially, is this distinction broadly made.

There, the naval architect and the military engineer form together a *corps de gênie*—the one called *gênie militaire*, the other *gênie maritime*—and these words clearly mark out that the original intention, invention and inspiration should be derived from a higher source than the mere execution of a practical work—the mere process of giving materials shape; or the details of putting them into place and fixing them there.

The *corps de gênie* has science, calculation and head-work as its business, as distinguished from the handiwork which requires mainly use and skill, but which, nevertheless, cannot dispense with head-work. The head-work must be done first, and the handiwork must follow after.

The naval architect has therefore done his work before the ship-builder begins. In fact, he may be said to have laid down "*the law*" of the ship, in lines so exact and well thought out that the slightest deviation would be an injury to her qualities and a drawback to her use. These lines, thus laid down, it is the business of the ship-builder truly to follow and soundly to execute, for as in the architect the highest quality was science and judgment, so in the ship-builder the highest quality is craft and skill.

The ship-builder, having first studied in the drawing what the ship is to be, must then make his selection of material, whether timber or iron. On this selection much of his skill depends; for durability of work, profit or loss, advantage or ruin, materially depend on selection. Timber is of all sorts—grown on good soil or bad, good or inferior, cut at the right season or the wrong, too young or too old, strong or decayed, durable or going to rot; and skill to know good from bad is a first requisite in a builder of wooden ships.

After *selection* comes *conversion*, the second point in the builder's craft.

A good converter hews out a fortune—a bad one wastes it. Some people waste twenty per cent., and some fifty. After a good converter the ship-yard will be found clean and tidy, most of the timber having been put into the ship. After a bad converter the yard will be in a litter, encumbered with loads of waste.

The timber selected and each part assigned to its use by the eye of a good converter, the work of the wooden ship-builder becomes comparatively easy. All the different pieces of timber of which the ship is to be composed having been collected in his ship-yard, the next stage in his business is a piece of exact geometry or shaping.

The geometry of ship-building consists mainly of two parts: *laying down* on the floor, and *taking off* from the floor.

Laying down consists in transferring the lines in the drawing to the mould-loft floor, but this is far from being a matter of mere routine or mechanical copy; it may be very skillfully or very stupidly done.

It is not a mere copy that is needed, though as a copy it must be exact; it is a copy with skill; a translation, as it were, from the language of the architect to the language of the craftsman—a translation from the *langue de gênie* into the *langue technique* and *mêchanique.*

Laying down on the floor, then, consists in taking from the architect's drawing all the precise points which his drawing has given, and expanding these to full size upon the floor of the mould-loft.

The scale of the architect's design is usually in this country and in England .0208, or one forty-eighth of the true size. In France, .02. In very large ships it is convenient to have the drawing smaller, say .0104 or .01.

The water-lines have no place in practical building, and what was everything to the architect is nothing to the builder. The architect's work takes the water for the basis; the builder's work lies on land, and he therefore works from the keel, not from the water-line.

The keel, therefore, is the first line he lays down on the floor. This line he lays even, straight and true with the greatest care, and from this all his work takes its position and shape. The ship's frames are drawn perpendicular to it; and parallels to it measure the heights of all the principal points above the keel; while a point on it is reckoned and marked as midship or ⊗. On this is erected the midship frame; and henceforth every line is reckoned above the line of the keel; every distance fore and aft from the plane of the midship section; and every breadth, starboard and port, perpendicular to the line of the keel. On this set of right-angled planes all the parts of the ship must be measured, drawn, moulded and shaped. For each frame of the ship there is now to be drawn a separate vertical section, and these vertical lines form the body plan, one line for each frame; though it may happen that not a single vertical section of the builder's draught will coincide with a vertical section of the design.

The building draught, then, gives the builder the outline, whether in wood or iron, of every transverse frame in the ship; but the skin or planking he has still to find by lines of his own. Some make the skin follow the water-line, and some make it follow the frames, so that the architect's lines have been taken and built in the *skin* of the ship as well as in the *frame;* but such methods have been found to be mechanical mistakes.

Much of the ease with which the ship will be formed, and no little of her strength, will depend on the wisdom with which the lines of the skin are selected and traced. These lines are called plank-lines or *ribband*-lines; they are intended to show the way the planks would lie most easily over the frame and keep most firmly in place with the least strain. For the strength of wooden planks it is necessary that they should lie easily, bend gently and fit snugly. The tendency of all plank when forced out of its natural shape is to resume that shape and so spring a leak. In iron ships, also, it is desirable not to twist the iron unnecessarily, so as to diminish its strength or increase its cost.

Therefore, to make the planks of a wooden ship or the long iron

plates of an iron vessel lie fair, great care must be taken to lay down the *ribband*-lines properly.

These two sets of lines—*frame*-lines and *ribband*-lines—are everything to the builder, and must go perfectly together, fit into and supplement one another, as they are really the elements which shape and decide nearly all the pieces of which the ship is composed; and they must be accurate to the minutest detail of the architect's design, though no one of them may happen to be found there.

It will be seen, therefore, that the drawing from which the builder is to construct his work is very far from being an enlarged and merely mechanical copy of the architect's design; it is rather a perfect translation of his idea, the practical result of which is the fulfillment of the design.

After "laying down" comes the work of the ship-yard, where lie the trees out of which the timbers of the ship are to be cut. The round timbers must be selected, the round slabs sawn off, the exact curve marked upon them by *moulds* brought from the *mould-loft floor;* and the trees being formed into the exact shapes for which originally *selected*, have now numbers and names, indicating their places, affixed to them; and when thus rendered fit to occupy their places are said to have been *converted.*

After *conversion* comes *erection.* Erection consists in assembling all the pieces of the frame—placing and fitting them to each other, and then uniting them temporarily in one, so that together they may be set on end upright upon the keel in the place where they are intended to go.

After *erection* comes *fastening.* To erect the frame is not enough; it must be held there.

It must be *fastened* to the keel, to its adjacent frames on both sides, to the *stringers, deck beams* and *planks;* but this fastening is gradual, and only ends when the ship is finished.

The frame erected has to be planked, or, if an iron ship, plated. The frames are the skeleton—the planking or plating, the skin.

It has to be shaped by the *ribband*-lines, bent to its curve, fitted snugly in place and fastened there. Then comes the caulking or filling the seams and keeping out the water. After which comes the *fitting* inboard and out.

The fitting of a ship is almost as extensive a part of the ship-

builder's art as the construction, and must be arranged beforehand by usage or contract, as it is by no means a mere matter of routine.

Finding is the next step. This applies of course more particularly to the merchant service. How a ship is to be fitted and found the special contract must state in clear terms, that no subsequent dispute may arise.

Finally comes *launching*, which is practically and legally the delivery of the ship, and is usually the epoch at which the property passes from the builder to the owner.

Here the duties of the builder end and those of the owner begin. The ship is then registered and named, turned over to her captain, equipped, stored, fitted and manned.

CHAPTER II.

MATERIALS FOR SHIP-BUILDING.

I. Iron.

Cast iron is the product of the process of smelting the different iron ores. From the smelting process result *slag,* or glassy matter formed by a combination of the flux with the earthy ingredients of the ore, and *pig iron,* which is a compound of iron and carbon, either unmixed or mixed with a small quantity of uncombined carbon in the state of *plumbago.* The ore is frequently *roasted* or calcined before being smelted to expel carbonic acid and water. The total weight of carbon in pig iron ranges from 2 to 5 per cent. of its weight.

Different kinds of pig iron are produced from the same ore in the same furnace under different circumstances as to temperature and quantity of fuel. A high temperature and a large quantity of fuel produce *gray cast iron,* which is further distinguished into No. 1, No. 2, No. 3, and so on—No. 1 being that produced at the *highest* temperature. A low temperature and a deficiency of fuel produce the *white cast iron.*

Gray cast iron is of different shades of bluish-gray in color, granular in texture, softer and more easily fusible than white cast iron.

White cast iron is silvery white, comparatively difficult to melt, brittle and excessively hard.

There are two kinds of white cast iron—the *granular* and *crystalline.* The granular can be converted into gray cast iron by fusion and slow cooling; and gray cast iron can be converted into granular white cast iron by fusion and *sudden* cooling.

Crystalline white cast iron is harder and more brittle than granu lar, and is not capable of conversion into gray cast iron by fusion and slow cooling.

Gray cast iron No. 1 is the most easily fusible, and produces the finest and most accurate castings. It is deficient in hardness and strength, and therefore, though suited to castings of moderate size, is inferior to No. 2 or No. 3 for large structures.

The presence of plumbago renders iron comparatively weak and pliable, so that the order of strength and stiffness among different kinds of cast iron from the same ore and fuel is as follows:

Granular white cast iron,	Gray cast iron No. 2,
Gray cast iron No. 3,	" " No. 1.

Crystalline white cast iron is unfit for engineering structures or machinery, on account of its extreme brittleness.

The strength of cast iron to resist *cross strain* is increased by repeated meltings up to the twelfth, when it falls off. The resistance to *crushing* increases by repeated meltings up to the eighteenth, when its strength is doubled, the iron then becoming silvery white and intensely hard.

The best course in order to obtain good iron is for the ship-builder or engineer to specify a certain minimum strength which the iron should show when tested by experiment. Good iron should show on the outer surface a smooth, clear and continuous skin, with regular faces and sharp angles. When broken, the surface of fracture should be of a light bluish-gray color and close-grained texture, with considerable metallic lustre. Both color and texture should be uniform, except that near the skin the color may be somewhat lighter and the grain closer. If the fractured surface is *mottled*, either with patches of *darker* or *lighter* iron, or with crystalline spots, the casting is unsafe, and it will be still more unsafe if it contains air-bubbles. The iron should be soft enough to be slightly indented by the blow of a hammer on an edge of the casting.

Castings are tested for air-bubbles by ringing them with a hammer all over the surface.

Iron contracts in cooling from the melting point down to the temperature of the atmosphere by $\frac{1}{96}$th part in each of its linear dimensions, or *one-eighth of an inch to a foot;* therefore patterns are made larger in that proportion than the intended pieces of cast iron which they represent.

Cast iron expands about $\frac{1}{900}$ or .00111 in rising from the freezing

to the boiling point. Every structure designed must have careful provision made for expansion and contraction.

Wrought or malleable iron is pure iron, all the impurities having been removed; the most common form of obtaining this sort of iron being by a process called *puddling,* in which the pig iron is melted in a "reverberatory" furnace and brought into close contact with the air by stirring it with a *rake* or "*rabble.*" Sometimes the iron is *refined,* before puddling, by having a blast of air blown over its surface while in a molten state. The process of refining removes part of the carbon, and leaves a white crystalline compound of iron and carbon called "*refiners' metal.*"

Sometimes the refining is omitted and the iron at once puddled; this is called "pig boiling."

The removal of the carbon is indicated by the thickening of the mass of iron, malleable iron requiring a higher temperature for its fusion than cast iron. It is formed into a lump called a "*bloom,*" taken out of the furnace and placed under a tilt or trip hammer, or in a suitable squeezing machine to be "*shingled;*" that is, to have the cinder forced out and the particles of iron welded together by blows or pressure.

The bloom is then passed between rollers and rolled into a bar; the bar is cut into short lengths, which are *fagoted* together, reheated and rolled again into one bar; and this process is repeated until the iron has become sufficiently compact and has acquired a fibrous structure.

Bars are called No. 1, No. 2, No. 3 bars, etc., according to the number of times they have been rolled.

In Bessemer's process the molten iron, having been run into a suitable vessel, has jets of air blown through it by a blowing machine. The oxygen of the air combines with the silicon and carbon of the iron, and in so doing produces enough heat to keep the iron in a melted state till brought to the malleable condition, when it is run into large ingots, which are hammered and rolled in the usual way. This process is most successful with the Swedish and Nova Scotia iron.

Strength and toughness in bar iron are indicated by a fine, close and uniform fibrous structure, free from all appearance of crystallization, with a clear, bluish-gray color and silky lustre on a torn surface, where the fibres are shown.

Plate iron of the best kind consists of alternate layers of fibres crossing each other. It should have a hard, smooth skin, somewhat glossy, and when broken should show perfect uniformity of structure and be free from all tendency to split into layers.

To examine the internal structure of iron, whether in bars or plates, a short piece may be notched on one side near the middle and bent double. The fitness of bar iron for ship-building and smith-work is tested by bending and punching it cold, and by punching and forging it hot, so as to ascertain whether it shows any signs of brittleness either when hot or cold, technically "cold short" or "hot short."

Good wrought iron loses strength by much reheating. Good bar iron has in general attained its maximum strength, and therefore the least possible amount of reheating and working in order to obtain any desired figure should be given.

Steel of different kinds is used in ship-building and machinery, but the limits of this work permit only an enumeration of some of the principal kinds.

Steel is the hardest of the metals and the strongest of known substances, being a compound of iron with from 0.5 to 1.5 per cent. of its weight of carbon.

There is, however, "steely iron" or "semi-steel," but these are compounds of iron, and are not *properly* steel.

Steel is distinguished by the property of *tempering;* that is, it can be hardened by sudden cooling from a high temperature and softened by gradual cooling, and its degree of hardness or softness can be regulated with precision by suitably fixing that temperature. The ordinary practice is to bring all steel to a high degree of hardness by sudden cooling, and then to soften it more or less by raising it to a temperature which is the higher the softer the articles are to be made, and letting it cool very gradually. The elevation of temperature, previous to the "annealing" or gradual cooling, is produced by plunging the articles into a bath of a fusible metallic alloy. The temperature of the bath ranges from 430° to 560°, Fahrenheit.

The following are some of the different kinds of steel: Blister steel, shear steel, cast steel, Bessemer steel, puddled steel, and granulated steel.

When the *tenacity* of iron is tested for purposes of ship-building, it is not considered fit for use if the specimen is broken by a less load

than 20 tons to the square inch of the original sectional area, or 24 tons on the square inch of the area as diminished by drawing out at the place of fracture. The better qualities of iron have greater strength than the above. It is also important that the *toughness* of the iron be tested by observing in what proportion the length of the piece is increased at the instant before breaking. The ultimate elongation of the best and toughest specimens of iron and steel is as follows, in fractions of the original length:

Bar iron, from	0.15	to 0.30
Plate iron, lengthwise, from	0.04	to 0.17
Plate iron, crosswise, from	0.015	to 0.11
Steel bars, from	0.05	to 0.19
Steel plates, from	0.03	to 0.19

The corrosion of iron is a sort of slow combustion, during which the iron combines with oxygen and produces *rust.* The ordinary methods of preserving iron in the air consists principally in preventing the access of oxygen to the metal.

The corrosion of iron is more rapid when partly wet and partly dry, than when wholly immersed in the water or wholly exposed to the air. It is accelerated by impurities in the water, and especially by decomposing organic matter or free acids. Cast iron and steel decompose rapidly in warm or impure sea water.

The following are some of the methods of preserving iron not immersed in sea water, hot or cold, nor exposed to hot steam:

1st. Boiling in coal-tar, especially if the pieces of iron have first been heated to the temperature of melting lead.

2d. Heating the iron to the temperature of melting lead, and then smearing it with cold linseed oil, which dries and forms a sort of varnish.

3d. Painting with oil paint, which must be renewed from time to time. The second process is a good preparation for this.

4th. Coating with zinc or *galvanizing.* This is efficient if not exposed to acids capable of dissolving the zinc; but it is destroyed by sulphuric acid in the atmosphere of places where much coal is burned.

II. Timber.

The tenacity of wood when strained "along the grain" depends on the tenacity of the fibres; the tenacity of wood when strained "across the grain" depends on the adhesion of the fibres or cells to each other.

When a woody stem is cut across the grain, the *cellular* and *vascular* tissues are seen to be arranged as follows: In the centre of the stem is the *pith*, composed of cellular tissue, enclosed in the medullary sheath, which consists of vascular tissue of a particular kind. From the pith there extend, radiating outward to the bark, thin partitions of cellular tissue called *medullary rays;* between these, additional medullary rays extend inward from the bark to a greater or less distance, but without penetrating to the pith.

When the medullary rays are large and distinct, as in oak, they are called "*silver grain.*"

Between the medullary rays lie bundles of vascular tissue, forming the woody fibre, arrayed in nearly concentric rings or layers round the pith. These rings are traversed radially by the medullary rays. The boundary between two successive rings is marked more or less distinctly by a greater degree of porosity and by a difference of hardness or color.

The annual rings are usually thicker at that side of the tree which has had most air and sunshine, so that the pith is not exactly in the centre.

The wood of the entire stem may be distinguished into two parts, the outer and younger portion called "*sap-wood*" being softer, weaker and less compact, and sometimes lighter in color than the inner portion called "*heart-wood.*" The heart-wood is alone to be used in work where *strength* and *durability* are required. The boundary between the sap-wood and heart-wood is in general distinctly marked, as if the change from the former to the latter occurred in a single year.

The following is taken from the *Encyclopædia Britannica*, article Timber:

Trees.	Rings of sap-wood.
English oak	12 to 15
Chestnut	5 or 6

Trees.	Rings of sap-wood.
Elm	about 10
Scotch fir	" 30
Memel fir	" 44
Yellow pine	" 42

There are certain characteristics of strong and durable timber, to what class soever it may belong. That specimen will in general be the strongest and most durable which has grown the slowest, as shown by the narrowness of the annual rings. The cellular tissue, as seen in the medullary rays, when visible, should be hard and compact.

The vascular or fibrous tissue should adhere firmly together, and should show no *wooliness* at a freshly-cut surface, nor should it clog the teeth of the saw with loose fibres. If the wood is colored, darkness of color is in general a sign of strength and durability. The freshly-cut surface of the wood should be firm and shining, and should have somewhat of a translucent appearance. A dull, chalky appearance is a sign of bad timber.

In wood of a given species the heavier specimens are in general the stronger and the more lasting. Amongst resinous woods those which have the least resin in their pores, and amongst non-resinous woods those which have the least sap or gum in them, are in general the strongest and most lasting.

Timber should be free from such blemishes as "*clefts*," or cracks radiating from the centre; "*cup-shakes*," or cracks which partially separate one annual layer from another; "*upsets*," where the fibres have been crippled by compression; "*rind-galls*," or wounds in the layer of the wood, which have been covered and concealed by the growth of subsequent layers over them; and "*hollows*" or spongy places in the centre or elsewhere, indicating the commencement of decay.

Among the different kinds of timber may be enumerated the following as superior to all others: *teak, live oak, English* and *African oak*, and oaks of Continental Europe. These woods are generally classed as twelve years when well seasoned. *Mahogany, ash and Cuba sabicu* are generally classed ten years. After which come *white oak, spruce pine, hackmatack, sweet chestnut, elm, fir, yellow pine* and many others. "Lloyd's rules" will show their relative values. The woods

most in use in this country are live oak, white oak, hackmatack, chestnut, elm, spruce pine and yellow pine.

Of all woods, the teak, live oak and English oak are the most valuable for ship-building purposes.

The best soil upon which to grow timber is one which, without being too dry and porous, allows water to escape freely, such as gravel mixed with sandy loam. The most injurious soil to trees is that of a swampy nature, containing stagnant water; it never fails to make the timber weak and perishable.

There is a certain age of maturity at which each tree attains its greatest strength and durability. If cut down before that age, the tree is not only smaller, but contains a greater proportion of sap-wood, while the heart-wood is less strong and lasting. If allowed to grow too long, the centre of the tree becomes either brittle or soft, and decay sets in. The following data are from Tredgold's tables:

	Age of maturity.
Oak	60 to 200 years—average 100 years.
Ash, elm and larch	50 to 100 "
Fir	70 to 100 "

The best season for felling timber is that during which the sap is *not* circulating—that is, in cold and temperate climates, *the winter*, and in tropical climates, the *dry season;* for the sap tends to decompose, and so cause the decay of the timber.

The bark (so say the best authorities) should be stripped off the preceding spring before felling.

Immediately after the timber has been felled, it should be "*squared,*" by sawing off four "*slabs*" from the log, in order to give the air access to the wood and hasten its drying. If the log is large enough, it may be sawed into halves and quarters.

Seasoning timber consists in expelling, as far as possible, the moisture which is contained in its pores. *Natural seasoning* consists in simply exposing the timber freely to the air in a dry place, sheltered, if possible, from sunshine and high winds. The seasoning-yard and the timber-shed floors should be paved and well drained, and the timber supported on stone or cast-iron bearers, and piled so as to admit of the free circulation of the air over all the surfaces of the pieces.

Natural seasoning to fit timber for carpenters' work usually oc-

cupies about two years; for joiners' work, about four years; but much longer periods are sometimes employed.

To steep timber in water for a fortnight after felling it, extracts part of the sap and makes the drying process more rapid.

The best method of *artificial seasoning* consists in exposing the timber in a chamber or oven to a current of hot air. In one process the current of hot air is impelled by a fan at the rate of about 100 feet per second, and the fan, air-passages and chamber are so proportioned that one-third of the volume of air in the chamber is blown through it per minute. The best temperature for the hot air varies with the kind and dimensions of the timber; thus, for

Oak, of any dimensions, the temperature should not exceed..............................	105° Fahr.
Leaf-woods in general, in logs or large pieces	90° to 100° "
Pine woods in thick pieces......................	120° "
" " in thin boards.......................	180° to 200° "
Bay mahogany in 1-inch boards..............	280° to 300° "

The time required for drying is as follows:

Thickness in inches...........................	1,	2,	3,	4,	6,	8,
Time in weeks.....................................	1,	2,	3,	4,	7,	10,

the current of hot air being kept up for *twelve hours per day* only.

Timber in seasoning loses from 6 to 40 per cent. in weight, and from 2 to 8 per cent. in transverse shrinkage.

Elm loses the most; oak, yellow pine and mahogany are next; larch loses the least.

All kinds of timber are most lasting when kept constantly dry and at the same time freely ventilated.

Timber kept constantly wet is softened and weakened, though it does not necessarily decay; there are some exceptions to this, however, as elm and live oak. The situation of alternate wetness and dryness, or of a slight degree of moisure accompanied by heat and confined air, is the least favorable to durability.

For pieces of carpentry which are exposed to these causes of decay, such as the planking of a ship's side, the stem and stern-post, timbers of the hold, etc., the most durable kinds of timber only should be employed, and proper precautions should be taken for their preservation.

Timber exposed to confined air alone, without the presence of any

considerable quantity of moisture, decays by "dry rot," which is accompanied by the growth of fungus, and finally converts the wood into a fine powder.

Among the most efficient means of preserving timber are good seasoning and the free circulation of air.

Protection against moisture is afforded by oil paint, *provided that the timber is perfectly dry* when first painted, and that the paint is renewed from time to time. A coating of pitch or tar may be used for the same purpose.

Protection against the dry rot may be obtained by saturating the timber with solutions of particular metallic salts. For this purpose Chapman (the Swedish architect) employed copperas (sulphate of iron); Mr. Kyan, corrosive sublimate (bi-chloride of mercury); Sir Wm. Burnett, chloride of zinc. The two last methods are generally known as the "Kyanizing" and the "Burnettizing" processes.

All these *salts* preserve the timber so long as they remain in its pores, but it would seem that they are gradually removed by the long-continued action of water. Dr. Boucherie employed a solution of sulphate of copper in about one hundred times its weight of water. The solution, being contained in a tank about 30 or 40 feet above the level of the log, descends through a flexible tube to a cap fixed on one end of the log, whence it is forced by the pressure of the column of fluid above it through the tubes of the vascular tissue, driving out the sap before it at the other end of the log, until the tubes are cleared of sap and filled with the solution instead. Timber is also protected by first exhausting the air and moisture from it in an air-tight vessel, and then forcing *creosote* (a kind of pitch oil) into the pores of the wood. The timber absorbs from a *ninth* to a *twelfth* of its weight of the oil. This is known as Bethell's process, and seems to be one of the best in use.

CHAPTER III.

SHAPING AND TOOLS FOR IRON AND WOODEN SHIP-BUILDING.

SHAPING *the frames* of iron vessels consists mainly in *cutting* or *shearing* the *angle-iron* bars to the proper length, *bending* them so as to give the proper figure to the moulding edge, and *beveling* them.

I. The *shearing* of angle iron is usually performed by a machine consisting of a fixed and movable cutter; the fixed cutter is of the form of a right-angled triangular notch, in which the angle iron to be cut is laid with the angle downward; the movable cutter is a solid right-angled triangle, with the right angle pointing downward; it is fixed in the lower end of a block which slides between vertical guides, and has a reciprocating motion given to it by an eccentric upon a rotating shaft, making twenty revolutions per minute or thereabouts. The effort required to shear a piece of iron is about 50,000 lbs. per square inch of the area of the shorn surface; the work performed is about equal to that effort multiplied by half the thickness of the piece in the direction of the shearing. For an equal area of steel the effort is probably about double.

II. The *bending* of angle-iron frames to any sharp curvature is usually done while hot, upon a level platform composed of large plates of cast iron called *leveling-blocks*, *leveling-slabs* or *leveling-plates*. These plates are completely covered with holes about $1\frac{1}{2}$ inches in diameter, and 4 or 5 inches apart from centre to centre. The wooden mould of a given frame having been laid on the leveling plates, the figure of the moulding edge is marked on them with chalk, and iron pins are stuck in the holes, so that when the iron rib is made to touch those pins it shall have the *proper* form. In order the more easily to produce any required figure, the heads of the pins are furnished with eccentric discs or cams, by the shifting and turn-

ing of which the figure of the frame can be adjusted with great precision. Every disc has several centre holes, any one of which can be fitted on the pin. The iron bar for the frame having been raised to a *bright orange heat* in a reverberatory furnace called a *reheating furnace,* is taken out by the smiths, laid on the leveling-plates and rapidly bent by means of tongs, hammers, mallets and levers, so as to lie touching the heads of the pins.

Care should be taken that just enough of air for complete combustion, and no more, is admitted into the reheating furnace, for any excess of air *burns* the iron. In fact, for the sake of safety against that evil, it is best that the supply of air should be slightly deficient, although the consequence may be that some smoke is given out.

III. *Cold bending* may be used when a slight, uniform curvature is to be given to a bar, or when a slightly bent bar is to be straightened. It may be done by means of a machine having a motion similar to that of the shearing machine already mentioned, and may be performed in either a vertical or a horizontal plane. One side of the bar to be bent or straightened rests against a pair of fixed blocks with slightly rounded surfaces. Midway between those fixed blocks the opposite side of the bar is pressed upon by a block having a reciprocating motion. The position of the fixed blocks and the length of stroke of the movable block are capable of adjustment according to the alteration to be produced in the figure of the bars. After each stroke of the movable block the bar is pushed or dragged forward through a distance equal to about half the space between the fixed blocks.

IV. *Beveling* of angle-iron frames, according to the bevelings given on the *beveling boards,* is performed by smiths while the iron is lying hot upon the leveling plates at the same time with the bending, and it is done by *opening* or *closing* the angle iron, according as the beveling forms an obtuse or an acute angle. This opening or closing is an operation not only difficult to perform correctly, but very straining to the material itself *at the angle,* and is *always* more or less injurious to its strength. It therefore requires careful superintendence; and special attention should be paid to the flatness of the outer or *faying* surface of the side arm of the angle iron, to which the plating of the ship is to be riveted; for if the opening or closing is carelessly done, that surface becomes concave instead of flat, and

the riveting of the plating to it cannot be made secure. Care should also be taken that the frames are not split at the inside or outside of the angle by the great strain that the process of opening or closing produces there.

Shaping plates consists chiefly in cutting them to the required size and figure, planing their edges and bending them. The figures and sizes of the plates should be shown on the *expansion of the skin*, on which their thicknesses should also be written or indicated by colors or shading. The plates should come from the manufacturer as nearly as practicable of the proper dimensions, so that there may be as little cutting needed as possible; but some cutting will always be required, especially near the ends of the vessel.

I. The *cutting* of plates is done by means of a shearing machine of sufficient size and power. The cast-steel cutters are both straight. The lower cutter is fixed and horizontal; the upper or movable cutter has a slight slope, so that the shearing of a plate begins at one side and advances by degrees toward the other.

II. *Planing* the edges of plates is required at butt joints, in order that the fit may be accurate and close, for the sake both of water-tightness and of the uniform distribution of compressive stress.

III. *Bending* plates, if the curvature is great, must be done after heating them in a reverberatory furnace of suitable dimensions; if the curvature is slight, it can be performed while they are cold by the aid of a machine. The plate, in passing through the plate-bending machine, rests upon and is carried forward by two horizontal rollers with fixed bearings and driven by suitable gearing. Between these rollers the upper side of the plate is pressed upon by a free roller, the positions of both bearings of which are independently adjustable by screws, so as to give any required curvature to the plate, whether cylindrical or conical, constant or varying.

Punching and *Drilling* are the means of making the holes through which the pieces of a ship's framework and skin are riveted together. In either of these operations two things have to be considered—*first*, the position and arrangement of the holes; and *secondly*, their figure and the means of producing it.

I. The *position* and *arrangement* of the holes, and especially their *pitch*, or distance apart from centre to centre, must be exactly the same in two pieces that are to be riveted together, the *slightest* want

of accuracy in their correspondence with each other being fatal to good workmanship. The bad practice of stretching with a *drift* on or over a pair of holes which do not truly correspond, so as to make a partial correction of the error, is never permitted in good ship-building. The oldest and simplest way of making the rivet-holes in two pieces correspond, where the holes are punched or drilled one by one, is as follows: The holes in one of the pieces having been made in the first place, the two pieces are laid together in their intended relative position; when plugs dipped in whitening passed through the holes of the first piece mark the spots on the second piece where the holes are to be made.

That process becomes unnecessary when machines are used which can punch or drill a whole row of holes of uniform pitch, so that when the two ends of the rows of holes in a pair of pieces correspond, all the intermediate holes correspond also.

II. *Figure of holes.*—Drilled holes are cylindrical, being of the same diameter throughout; punched holes are conical, being of the diameter of the punch at the side where it goes in, and of a somewhat greater diameter at the opposite side, where the piece of metal from the hole drops out. The diameter of a punched hole at the large end is equal, or nearly so, to that of the hole in the *die*, or perforated plate of steel on which the plate or bar rests that is being punched.

In order that the punching machine may work easily, the die must be at least from $\frac{1}{16}$ to $\frac{3}{16}$ of an inch larger in diameter than the punch; and by making the die wider still, holes of any degree of taper required in practice may be punched; but it is only the smaller end of a punched hole that is perfectly accurate in diameter and position; the larger end is apt to be somewhat irregular, and, if it widens very much, to be more or less rough and ragged. In other respects the conical form of the punched holes is advantageous, as enabling the rivets to hold the plates more firmly.

Hence, where *three* or *more* layers of plates or bars are to be riveted together, it is advisable, for the sake of accurate fitting, that the holes should be drilled and not punched, except in the outermost layers; but where *two layers only* are to be riveted together, punched holes will give a more firm fastening, provided *the small ends of the holes are placed together.* Hence the indispensable rule, that *all*

punched holes should be punched from the faying surface of the plate or bar—that is, from the surface which is to touch that of the piece to which it is to be riveted. In a piece with two faying surfaces, the holes should be drilled.

The outer ends of all rivets in the outside plating of an iron ship are *counter-sunk,* and for that purpose the holes in the outer plates must have a conical enlargement, which is sometimes drilled with a conical tool called a *counter-sunk* drill, and sometimes made simply by punching the hole of a sufficiently spreading conical form. In either case the hole should have the same figure; that is to say, there should not be a mere conical counter-sink for a small depth inward from the outward end of the hole, but *the entire hole should form one cone;* and in order that the rivet after its contraction in cooling may not only hold the plates together, but continue to fit the hole in the outside plate with equal tightness, *the apex of that cone should be in the plane of the inner surface of the innermost piece through which the rivet passes.* See figs. 1 and 2.

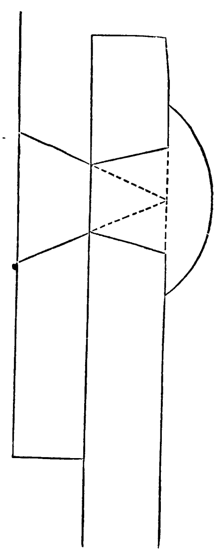


FIG. 1.

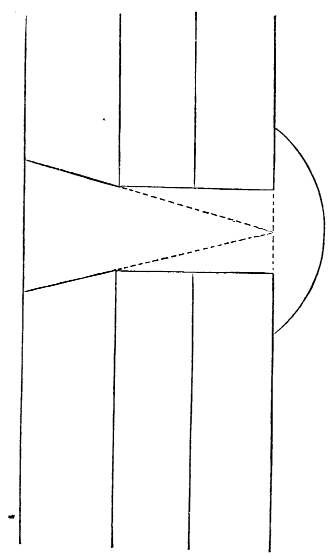


FIG. 2.

Plates and bars more than one inch thick are almost always drilled, and not punched.

The force required to punch a hole in strong wrought iron is about 50,000 lbs. for each square inch of the fractured surface, as in the case of shearing; and the work done is nearly equal to that force multiplied by half the thickness of the plate or bar.

Shaping Timber.

By the *conversion* of timber is meant the cutting (in general, with the saw) of logs of timber into pieces nearly of the shape required in ship-building.

Great experience, judgment and care are necessary on the part of the *converter* who conducts this process, in order that he may, in the first place, select the logs best suited for given purposes, and then cut up those logs in the most efficient and economical way.

The following are the chief principles to be attended to in converting timber:

I. Every piece is to be *as little grain-cut as possible;* in other words, the natural figure of the fibres of the wood should approach as near as possible to that of the principal piece to be cut from it; thus, long and straight logs are to be used for *keels, keelsons,* etc., and for sawing into *planks* and *thick stuff*; shorter straight logs for *beams, stern-posts,* etc.; more or less curved (or *compass*) pieces for *stems, futtocks, transoms,* etc.; and the most crooked pieces for *hooks* and *knees.*

II. Besides cutting one or more principal pieces from a log in the best possible way, regard should be had to the economical conversion of the remainder of the log into smaller pieces, such as *chocks, carlings,* etc.

III. Regard should be had to the blemishes of the timber in converting it. If these are of a bad kind, and especially if they consist in decay, the blemished parts must be cut out and rejected. *Clefts* and *shakes* of small extent, in a large piece of timber, may be prevented from injuring its strength much, if care be taken to convert it in such a manner that the damaged places shall be near the middle of the depths of the piece.

IV. For *thick stuff* and *planking,* unblemished and straight-grained timber alone should be used. In sawing timber with "silver grain" or large medullary rays, into planks, care should be taken that the silver grain does not quite run through the planks, otherwise they will be liable to be split by the fastenings.

V. As the top of a log is naturally more durable than the butt, the butts of pieces of timber should, as much as possible, be placed in those situations in the ship's framing which expose them least to causes of decay; for example, the butt of a log should be the heel rather than the head of the stern-post, because wood lasts longer when always wet than when alternately wet and dry.

Steaming and Bending.—In the scarcity of naturally crooked timber, pieces of wood may be bent artificially, having first been softened by steaming or boiling. On being again dried, while in the bent position, the timber recovers its hardness and retains its curvature.

The bending apparatus may be varied very much in detail; but essentially it consists of two rounded cast-iron blocks pressing upon that side of the timber which is to be convex, near its ends, and one, two, three or any required number of such blocks pressing against the intermediate parts of that side of the timber which is to be concave, the position of each block being adjusted to the required curvature by means of a powerful screw. So far as the fibres of the wood are *compressed* while in the soft state, it is found that their strength is but little impaired; but so far as they are *stretched* to any material extent, they are permanently weakened. To prevent this evil, before the bending is commenced a piece of plate iron, BB,

FIG. 3.

(fig. 3) of the same breadth with the timber, and somewhat longer, is placed in contact with that side of the timber which is to be made convex; and to that plate are riveted or bolted a pair of angle-iron abutments, CC, in close contact with the ends of the timber. When the timber thus guarded is bent, the iron plate and abutments prevent any appreciable stretching of its fibres, so that the whole bending takes place by compression; and the result is, that the bent timber is not sensibly weaker than a naturally bent piece of the same figure.

The *forming* and *trimming* of timbers consist in taking the con-

verted pieces of wood and shaping them exactly to the required figures by first *siding* them, or giving them the correct breadths; secondly, *moulding* them, or giving them the correct outlines and depths; and thirdly, *beveling* them, where that operation is required.

Pieces that lie or stand amidships, like the keel, stem, stern-post, dead-wood, keelson, etc., are sided by laying off the half siding each way from a central plane. They are then moulded by being cut to the shape and dimensions of the *moulds* furnished from the *mould-loft*, which show not only the outlines of the several pieces, but the forms and positions of the *scarphs* by which they are to be joined together.

The stem, with the dead-wood and other adjoining pieces, having been *tree-nailed* and *coaked* together, the stations for hooks and for *cant-frames* are marked on them, and the *rabbet* for stepping the cant frames is cut. The same description applies to the dead-wood and other pieces adjoining the stern-post.

Pieces that have a moulding side, such as *frame timbers*, are in the first place trimmed truly plane, or "out of winding," as it is called, on the moulding side; the siding is then laid off from that side; then the mould is laid upon the moulding sides of the timber, and the moulding edge drawn and cut to its true figure; then the *sirmarks*, or points of intersection of the moulding edge with the *ribband-lines*, and the other beveling points are marked; then the depths are laid off so as to enable the inner edge of the moulding side to be drawn and cut; and lastly, the piece is trimmed to the true beveling, which is shown for each sirmark, etc., on the beveling board, and is transferred to the timber by the aid of the *bevel*, an instrument consisting of two straight-edge pieces hinged together—one called the *stock*, which is applied to the moulding side, and at right angles to the moulding edge; and the other called the *tongue*, which is set so as to form the proper angle of beveling with the stock, and which touches the beveling surface of the timber when it is correctly formed.

Coaks.—Where two pieces of timber are to be connected by a cylindrical *coak* or *dowel*, they are laid together in their proper relative position, and a hole is bored with a small auger through both pieces at once, to mark the centre of the coak; then a hole of the diameter and half depth of the coak is bored from the *faying* surface

of each piece with a *drilling tool* of the proper size, in what is called a *dowel engine.* The cylindrical coaks themselves are *turned* out of hard and durable wood.

A *mortise,* or *sunk coak,* is a hollow cut in a piece of timber to fit a *tenon* or *raised coak* on another piece. This is usually known as *tabling.*

When cut by hand, mortises and tenons are generally rectangular; when a mortise is cut by machinery, it is *often* oblong, with semi-circular ends, being made by means of a boring tool which has a traversing motion from side to side equal in extent to the length of the straight sides of the mortise. Square mortises, however, are sometimes cut by a machine tool, consisting of a hollow square chisel having an auger working through it, which removes the chips produced by the chisel along with those produced by its own action.

Tree-nails are turned out of hard, strong and durable timber, such as the best oak, teak or locust. The only woods suited for this purpose are those which have considerable strength *across* as well as *along* the grain. The diameters of tree-nails range from 1 inch to $1\frac{3}{4}$ inches.

Compressed tree-nails are made by a machine in which, after having been softened by steaming, they are forced in at the larger end and out at the smaller end of a tapering steel tube, so as to reduce them to about two-thirds of their original diameter. Upon being again moistened, they gradually swell out to their former size. They make a very tight fastening, but are not to be used except in large and thick pieces of timber, lest by swelling they should split the pieces they are used to connect.

Shaping machines for wood.—The most generally used machines for working in timber are *saws* of different kinds. Those for making straight cuts, as where the timber is to be sawed into planks, may be either *circular* or *reciprocating.* The log to be sawed is supported in a movable frame called a *carriage,* by the slow motion of which it is *fed* to the saw. The feed motion to circular saws is usually horizontal; to reciprocating saws, either horizontal or vertical, according as the saw is vertical or horizontal. A vertical saw usually cuts during its down stroke only, and the feed motion therefore takes place wholly during the *down stroke,* and ceases during the *up stroke.* A horizontal saw may cut both ways, and then the feed motion is continuous;

and the motion of the saw, which is straight, takes place upon *guides* slightly curved in a direction *convex* toward the advancing log, in order that the cutting action of *each tooth* of the saw may take place in a direction toward the centre of the log, and that at the same time the order in which *successive teeth* of the saw come into action may be from the centre to the outside.

Reciprocating machine saws should have the reactions due to their motions carefully counterpoised, so that there may be a "running balance" as well as a "standing balance," otherwise the machinery when working fast will overstrain both itself and the building.

A machine saw for cutting out *compass* or *curved* timber is usually an endless flexible *band* of steel with saw teeth on its edge, carried and driven by pulleys, and passing downward through a hole in a cast-iron table. A piece of wood being placed on the table and properly guided, may have a saw cut made in it of any required figure; and by tilting the table, or inclining the band saw, or by both motions combined, the cut may be beveled in any required manner.

In *shaping machines* for cutting long pieces of timber to cross sections suited for *plank-sheers, rails, thick water-ways*, etc., the timber is usually fed horizontally by a carriage moving like that of a sawing machine to a set of rapidly rotating discs armed with steel cutters resembling chisels and small edges; the arrangement of the discs and cutters is capable of being varied, so as to produce different forms of cross section.

CHAPTER IV.

ON LAYING DOWN AND TAKING OFF.

THE operation of "laying down" consists partly in making full-sized drawings of the *frame* and *skin* of a ship upon the floor of the *mould-loft,* and partly in the construction of *moulds* and *beveling boards* for various pieces of the frame; *moulds* being full-sized patterns of the same figures and dimensions as the moulding sides of the pieces which they represent, and *beveling boards,* flat pieces of wood on which the *bevelings* of the several pieces are marked. The object is to provide full-sized representations of the several parts of the ship, so that, when the timber or iron is shaped from these representations and put together, a ship shall be formed agreeing *exactly* with the design of the naval architect.

I. *Full-sized drawings* are made on the carefully leveled and planed floor of the mould-loft. Lines for temporary purposes are usually drawn with chalk; lines which are to be permanent are *razed* or *scribed* on the floor with a pointed tool called a *scriber.* The drawings on the floor should be made from the "*building draught,*" or they may be made directly from the "*calculation draught*" or from a "*water-line model.*"

In the mould-loft drawings, the full size and moulding edge of every frame must be shown. After a few of the principal frames have been drawn, the intermediate frames must be marked at their stations in the sheer and half-breadth plans, and their figures marked in the body-plan by the aid of a sufficient number of level-lines, buttock-lines or ribband-lines, the last being the most commonly used. The point where a ribband-line cuts a frame is called a *sirmark.*

II. *Fairing the body.*—The greater scale of the full-sized drawing makes any want of fairness in the ship's lines more conspicuous in it

than in the building draft. Therefore, when a set of lines requiring fairness, whether *water-lines, level-lines,* buttock-lines or ribband-lines, have been copied in chalk from the building draft on to the mould-loft floor, they are to be *"faired"* before being razed in; that is to say, any small irregularities of figure which were invisible on the paper are to be smoothed away by the eye or by the aid of an elastic batten. The *ordinates* of the lines, as thus faired, are to be used in constructing the full-sized body-plan. A batten should never be left pinned around a curve for a longer time than is absolutely necessary, lest its elasticity should be impaired.

III. *Additional ribband-lines.*—The full-sized drawing must show not merely the figures of the parts of the frame of the ship, but the arrangement of the pieces of material of which those parts are to be built up, especially when that material is timber. For example, each of the frames of a wooden ship is made up of several lengths of timber called *floors, futtocks,* etc. The joints where these pieces are connected together are so arranged as to lie in a series of diagonal lines; and there are thus as many diagonal lines as there are pieces in a frame or rib, less one. It may not be necessary to draw all these diagonal lines on paper, but *on the floor they must all be drawn.*

IV. *Various additional lines.*—The moulding edges of such pieces of the frame as *cant frames, counter-timbers, breast-hooks, transoms,* etc., must all be laid off on the mould-loft floor.

V. *Arrangement of the plans.*—The mould-loft floor is seldom large enough to show the plans of a vessel arranged in the same way as on paper; and hence their arrangement has to be modified in order that they may be contained within the available space. For example, the half-breadth plan, instead of being placed below the sheer-plan, has its base line so placed as to coincide with the base line of the sheer-plan; and the lines of these two plans are thus mingled together. The two halves of the body plan, too, are sometimes drawn within one-half the *moulded breadth,* by being so arranged that the line representing the upright axis in each half of the body shall coincide with the vertical line touching the other half at its extreme breadth. The sheer plan and half-breadth plan are divided into as many divisions as the length of the ship compared with that of the floor may render necessary; and each such division has a few stations

at each end common to it and the adjoining division, to facilitate the fairing of the lines.

VI. Some differences in the manual operations of drawing on the floor and on paper arise from the difference of scale. For example, when straight lines on the floor are too long to be drawn by a straight-edged ruler, they are marked by means of a chalked cord. If the ordinates are found by *calculation*, the full-sized drawings may be laid off at once from a table of calculated ordinates, without the necessity of copying from a drawing on paper.

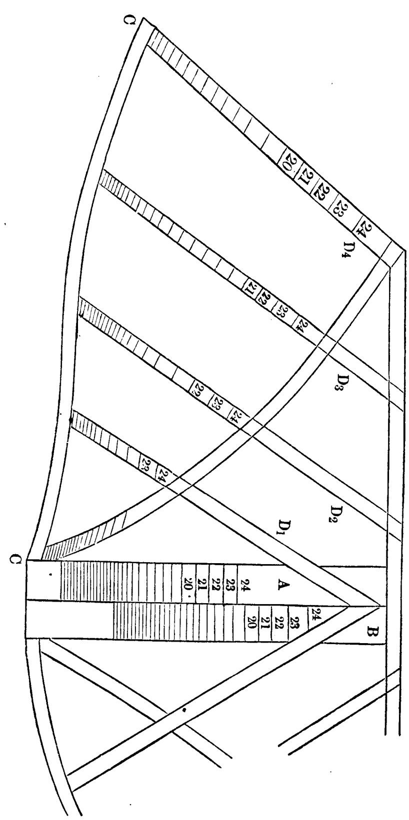


FIG. 4.

Moulds are often, for the sake of lightness, composed of a skeleton framework of battens, having just strength and stiffness enough to preserve a correct figure; and in the case of frames, one mould is so contrived as to serve for several frames. For example, fig. 4 represents a *floor mould* which is a portable copy of the lower part of the full-sized body plan.

It consists of two similar halves, one only of which is completely shown, hinged together at the vertical joint between the pieces A and B, which joint represents the longitudinal midship plane of the ship. The breadth of each of the pieces, A and B, represents the half siding of the broadest part of the keel. The transverse lines marked upon the piece A, and numbered, show the heights at which a series of frames, numbered consecutively up to 24, spring from the rising line or stepping line; the

corresponding transverse lines on the piece B show the heights at which the inner surfaces of the same frames meet the cutting down line. The lower edge of the batten, CC, represents the moulding edge of the floor part of the midship frame. The upper edge of the diagonal battens, $D_1D_2D_3D_4$, represents ribband-lines on the body plan; and upon these battens are drawn and numbered lines marking where they are crossed by the series of frames already mentioned.

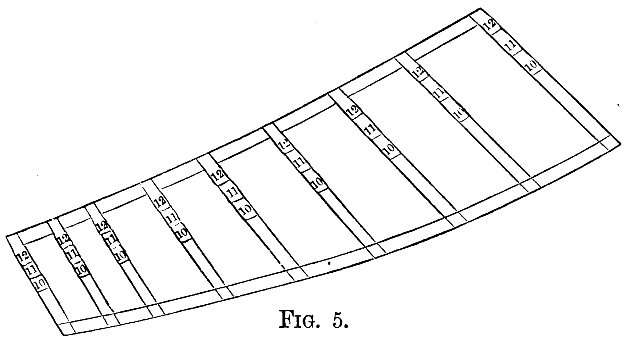


FIG. 5.

Fig. 5 exemplifies a *futtock mould.* The upper edges of the diagonal battens represent ribband-lines, as before; the outer edges of the two curved battens represent the moulding edges of portions of two frames; and the figures of the frames, intermediate between those two, are shown by the numbered lines marked across the diagonal battens.

When a part of the ship's frame is built up breadthwise as well as lengthwise of several pieces of timber (as is the case with the deadwood forward and aft), the mould is a flat board whose outline is the same as that of the part represented by it, and on which are drawn lines showing the "shift"—that is, the arrangement of the pieces of which that part is to be built.

Beveling-boards.—The "bevelings" of the ship's frames at a sufficient number of points having been determined, are marked upon a series of "beveling boards" such as that represented in fig. 6. The distance between the parallel lines, AB and CD, is equal to the half siding of the frames to which the board

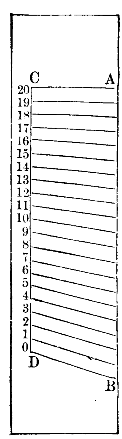


FIG. 6.

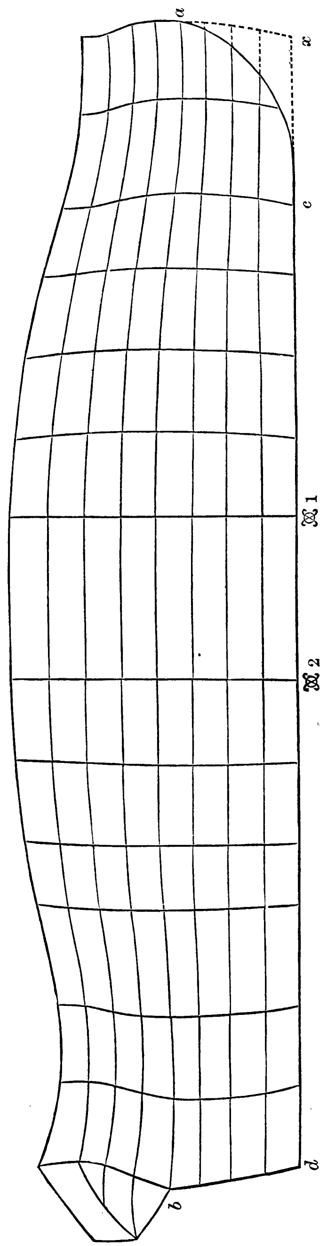


Fig. 7.

belongs; and the numbers of those frames are marked opposite to a series of lines, which make angles with AB equal respectively to the bevelings of those frames at some particular ribband-line. Each beveling-board is marked with a number or letter showing the ribband-line to which it belongs.

Expansion of skin.—To draw a full-sized expansion of the ship's skin, a skeleton diagram is first prepared. The process of expansion is applied to the skin of an intended ship in order to facilitate the laying off of the dimensions and positions of the pieces of which that skin is to be made, whether timber planks or iron plates. According to the ordinary construction of ships, the seams of the skin are nearly longitudinal, and most of them run continuously from stem to stern, the lowest being where the *garboard strake* fits into the rabbet of the keel; and the *butts* are parallel, or nearly so, to the adjoining frames. Fig. 7 represents an expansion diagram suitable to that style of construction. The nearly upright lines represent *frames;* the longitudinal curves, *seam-lines; ac* is the mid-rabbet line of the stem, *cd* that of the keel, and *db* that of the stern-post; and the curved boundary rising above *b* is the centre line of the skin of an elliptical stern. A

straight *middle body* is represented between $\otimes_1$ and $\otimes_2$. The midship frames are represented by vertical straight lines.

Seam-lines of the bottom should coincide with or be *normal-lines* crossing the frames at right angles; *first,* because when such is the case, the strakes of plank or of plate, when bent to fit the bottom, are curved *flatwise* only, and have no curvature *edgewise* (which curvature, when concave upward, is called *sny,* and when concave downward, *hang*); and *secondly,* because the particles of water in general tend to follow nearly the course of normal-lines, so that the overlapping edges of the strakes of *clinker-built* vessels cause, on the whole, less resistance in that position than in any other.

The seams of the upper part of the side must follow the sheer of the *topside, gunwale, portsills* and other *sheer-lines.*

To make the expansion diagram, therefore, the constructor commences by drawing on the body plan the projections of a series of sheer-lines to guide the seams of the side, and of normal-lines to guide the seams of the bottom. He next constructs the *development* of those seam-lines; then, by measuring distances on the *body plan* from the mid-rabbet of the keel round the frames to their points of intersection with the seam-lines, and on the development drawings round the seam-lines, from the midship frame to the same points, he is enabled to construct a figure like that of fig. 7.

Parallel to the longitudinal and transverse lines of that diagram are to be drawn the *seams* and *butts* of the plating or planking—proper *shift* being given in every case.

To measure the length of a curved line on the mould-loft floor, a *batten* is pinned along the line, and has marks made upon it at the two ends of the part to be measured. The batten is then set free, and the distance between the marks is measured when straight.

Laying off from a water-line model.—The curved surface of a model to be used in laying off usually represents the *inner* surface of the ship's skin, and the dimensions of the model the *moulded* dimensions of the ship. The vertical side of the model shows the sheer plan; and upon it are to be drawn a series of vertical lines representing the stations of a number of frames sufficient to determine correctly the figure of the vessel. The sheer plan, as thus completed, is now to be drawn to its full size on the mould-loft floor. The next operation is to take the layers of the model apart, and draw, upon

their horizontal surfaces, ordinates at the stations of the frames already marked. These ordinates, being measured by the proper scale, give the half-breadths at the points where the several frames intersect the several water-lines and sheer-lines; and those half-breadths are to be written in a table.

From the table of half-breadths the water-lines and sheer-lines are now to be constructed of the full size upon the half-breadth plan, and *faired* by the use of battens. The process of fairing may slightly increase or diminish some of the half-breadths; and the half-breadths as thus faired are to be entered in an amended table. The full-sized body plan is then constructed with the half-breadths as faired; and the remainder of the process presents nothing peculiar.* The tables of half-breadths may be used in the computation of moulded displacement and in other calculations.

Normal-lines are easily drawn on a model by means of a spring or whalebone batten.

By *taking off* is meant the operation of performing such measurements upon an actual ship as shall enable her plans to be drawn. The process just described is in some points similar, in some different, since the measurements have to be made from without instead of from within.

For the purpose of taking off, straight pieces of wood are fixed in suitable positions near the ship, so as to enclose it in a sort of rectangular cage. Some of these are horizontal, or nearly so, and are called *base-boards;* others are vertical, or nearly so, being at right angles to the base-boards, and are called *perpendiculars.* Distances are measured outward along the upper edges of the base-boards, and upward along the inner edges of the perpendiculars; and from the ends of those distances ordinates are measured inward to the external surface of the ship; and these measurements, being entered in a table, furnish the means of drawing her "calculation draft."

To find the figure of the stem, a base-board is fixed running out forward in continuation of the lower edge of the rabbet of the keel, and a perpendicular rising from that base-board a short distance ahead of the stem. Then, by measuring "*distances forward*" along the base-board, with "*ordinates up*," and also "*distances up*," along

* The operation of "laying down" can be learned thoroughly *only* by practice in the mould-loft.

the perpendicular, with "*ordinates in*," data are obtained for drawing the stem outside of the rabbet. By similar operations, the figure of the stern-post outside of the rabbet, and that of the stern above the post, are determined; and from these measurements, together with the depth of keel below the rabbet, the outlines of the sheer plan can be drawn.

To obtain a series of transverse sections, base-boards are fixed running out at right angles to the keel, at suitable intervals apart, such as 10 or 12 feet, and perpendiculars rising from those base-boards so as just to clear the ship's side. Then by measuring "*distances out*" along the base-boards, with "*ordinates up*" and "*distances up*" along the perpendiculars, with "*ordinates in*," data are obtained for constructing the body plan; from which, together with the sheer plan, the half-breadth plan can be constructed, thus completing the calculation draft of the ship; and from this draft and thickness of the skin, the building-draft may be deduced if required.

CHAPTER V.

SHIP-BUILDING YARDS.

In a ship-yard it is desirable that all that part of the ground which may at any time have to be used for building-slips should slope uniformly toward the water at an inclination equal, or nearly equal, to the steepest intended inclination of the sliding-ways.

In order that the errors of the compass in iron vessels may be as small as possible, the slips on which iron vessels are built ought to lie in the magnetic meridian, with the stern of the ship toward the nearest pole of the earth (the north in north latitude); and every iron-clad ship should be armor-plated with her head in the contrary direction to that in which it lay while building,

When there is a quay embankment or roadway between the yard and the water, small and light vessels may sometimes be launched over it; but for the purpose of launching large and heavy vessels, it is necessary to make a temporary opening in the quay or bank.

A building-slip is usually covered by what is called a *ship-house* in most navy-yards, and should generally be covered in private yards by a shed supported by tall posts. This is for the shelter of the ship and workmen, and is specially useful where a wooden ship is to be left "*in frame*" to season for any considerable length of time. Exposure to the alternate action of sun and rain is very injurious to a wooden ship. The designing and erection of the ship-houses or sheds is properly work for the civil engineer.

Their framework may often be made use of to support traveling cranes for carrying the pieces of material to their proper places in the ship, and also to support scaffolding for the use of the workmen. In building large ships much of the cost of scaffolding and gangways round the ship may be saved by using movable platforms, hanging

by tackles between properly stayed poles; each such platform being hauled up or down to the place where it is wanted for the time. The remainder of the yard, where workshops and stores are to stand, should be level or nearly so. In laying out the various parts of the yard, one object should be to make every piece of material, as far as possible, travel continuously onward from its entrance into the yard to the ship of which it is to form part; hence, as a general rule, the entrance should be at the end of the yard farthest from the water; next to the entrance should be the stores for raw material, timber-sheds, etc.; then the workshops and tool-sheds, in the order of the operations performed in them; and then the ground for the building-slip. Mould-lofts, pattern-rooms, model-rooms, drawing-offices and stores for tools and for finished parts of the ship's equipment, should be placed so as to be easily accessible, both from the workshops and from the building-slips, yet so as not to interrupt the direct communication between them.

When a number of machine tools can be kept constantly at work upon a succession of pieces of material that are carried continuously onward from the store to the tool, and from the tool to the ship, those tools are most economically driven by means of one steam engine, the power from which is transmitted to the several tools through *shafting* and belts.

CHAPTER VI.

BUILDING-SLIP—BLOCKS ON WHICH THE SHIP IS BUILT—LAYING THE KEEL AND RAISING THE STEM AND STERN-POST.

A SHIP is usually built upon a piece of ground called a *slip*, which in most cases slopes lengthwise toward the water. The slip should have a firm foundation, and, if possible, a floor of masonry, concrete, timber or iron. Perfect solidity of the slip is essential to the strength and safety of the vessels built upon it.

To support the keel of the ship, a row of temporary building-blocks, four feet apart, or thereabouts, from centre to centre, is placed. Each block is built of pieces of timber one above another; the lowest and largest of them are called *groundways*, and are from 12 to 15 inches square; and unless the foundation is so firm as to make it unnecessary, they lie lengthwise and form a platform of timber under the ship of 4 or 5 feet breadth.

The other pieces lie athwartships; they gradually diminish in size, and are more or fewer in number according to the height of the block, the uppermost being called *caps*.

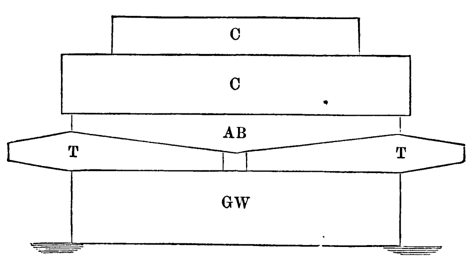


FIG. 8.

With a view to the future launching of the vessel, the blocks are made capable of being removed from below her keel. Fig. 8 is a

thwartship view of a block—GW *groundways,* CC *caps,* AB *angle-blocks* faced on the lower side with a thin plate of iron; TT wedges called *templates,* which rest on the groundways and support the angle-block. When the block is to be struck or removed, the templates are knocked out, which removes the support from the angle-block and the pieces above it. When angle-blocks are not used, the removal of the blocks is effected by splitting the caps.

In order that the workmen may easily get at the bottom of the ship, the lowest block is usually made about *two feet* high, and is generally under the forefoot of the ship; the heights of the other blocks depending on the inclination of the ship and of the keel.

Three rates of inclination have to be attended to in building a ship; that of her keel, that of the intended *sliding-ways* on which she is to be launched, and that of the slip.

The inclination of the ship's keel, when it is not intended to launch her on her keel, is a matter of choice and convenience; it is usually about 1 in 19 or 20, descending toward the water.

The object of making it descend toward the water is, to avoid excessive height in the building-blocks at the lower end of the slip, and to give the ship a bearing on the water as soon as possible when she is launched.

Should it be intended to launch the ship on her keel (as the French do), the inclination of the keel must be the same as that of the sliding-ways.

The ordinary *inclinations of the sliding-ways* are as follows:

For the smallest vessels....................	1 in 12 to 1 in 14,
" average vessels..........................	1 in 16,
" the largest vessels......................	1 in 20 to 1 in 24,

and the inclination of the sliding-ways is made gradually flatter for larger vessels, to prevent them from acquiring an excessive speed when they are launched.

The inclination of the *floor* of the slip is very much a matter of convenience; but it is usual to make it steeper than the steepest inclination of the sliding-ways required for launching the smallest vessel that is to be built upon it; that is to say, about 1 in 9 or 10.

This, however, is not absolutely necessary, provided care is taken to adjust the height of the blocks so that the forefoot of the vessel

in launching shall clear the lower end of the slip by about 9 inches. The heights of the blocks are determined by constructing a sheer plan of the ship, as shown in the sketch, fig. 9, in which HH rep-

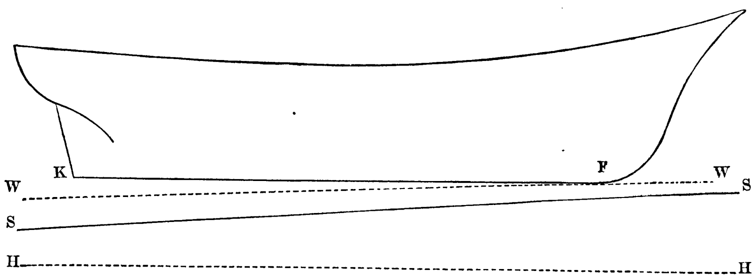


FIG. 9.

resents a horizontal line, and KF the lower side of the *false keel* at its intended inclination. Through F, the *forefoot* of the vessel, draw WW at the intended inclination of the sliding-ways; this will represent the line of the forefoot in launching. Set off 2 feet vertically downward from F to represent the height of the foremost block, and through the point thus found draw SS at the inclination of the slip. If SS is nowhere nearer to WW than 9 inches, the forefoot will pass sufficiently clear of the ground in launching; if not, the height of the foremost block must be increased.

The heights from SS to KF at the stations of the several blocks will show the height of those blocks; and in flat-floored ships care must be taken to give sufficient height to the midship blocks, to enable the work of that part of the bottom to be done easily and well.

The foregoing is, of course, based upon the supposition that the ship is to be launched in the ordinary way, stern foremost; so that she is to be built with her head at the upper end of the slip.

If she is to be launched head foremost, she must be built with her stern at the head of the slip.

Ships (like the "Great Eastern," for instance) are sometimes launched "broadside on;" and then the inclination of the slip must run athwartships, and its floor must be level longitudinally.

Or a ship may be built in a dock and, when complete, floated by the admission of water, instead of being launched; of course the floor of the dock must be level both ways.

Building-blocks of 4 or 5 feet high and upward are stayed in a fore-and-aft direction with oblique *shores*, to prevent them from tripping.

The keel of a wooden ship in this country is usually composed of *white oak*, and in England of *elm*, a wood which preserves in water, and the fibres of which are tough and well adapted to receive the numerous fastenings which pass through it. The size of the keel varies according to the size of the ship—from 20 inches square (or 20 inches sided and moulded) to 8 inches square, and even less.

The number of pieces depends, of course, upon the length of the ship and the stock of timber on hand. In a first-rate ship of the present day there may be as many as 10 pieces.* The forward piece has the fore end curved up so as to form what is called the *boxing* or *overlap* of the keel with the stem. This mode of uniting the keel and stem is called a *boxing scarph.*

The scarphs along the *tread of the keel* are called *tabled* scarphs, and are formed as follows: *ab* (see fig. 10) is the overlap or length of the scarph of one piece of the keel, *cd* the overlap of the other, *a* a sunken groove, in dimensions one-third the width of the piece, and one-half of the length of the scarph, the depth being one and a half inches; *b* the wood left above the plain surface *ef*, equal in size to the hollow *a*; the surface of the scarph of the other piece has the raised wood at *c*, and corresponding sunken groove at *d*; when these two surfaces are brought together, the groove *a* receives the raised wood *c*, and the groove *d* receives the raised wood *b*, thus locking the two pieces of keel together, the abutment *gh* of 3 inches resisting any strain brought on the pieces of keel to pull them apart. The length of the scarph is determined by the distance between the timbers of the ship, the scarph being long enough to take two of the bolts through the keelson.

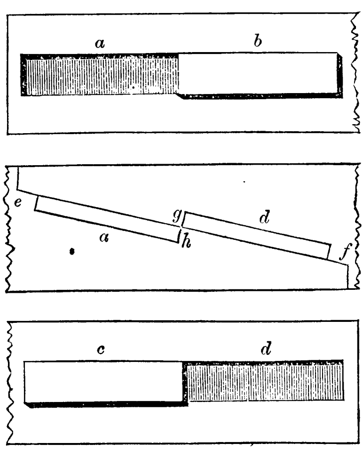


FIG. 10.

* The "Merrimac's" keel was in seven pieces, each over 40 feet long.

The *keel* in *iron ships* has various forms. When it is a plain bar, the lengths of which it consists are either welded or scarphed together, the plane of each scarph being vertical. When it is built of various pieces, such as plates and *angle-irons,* they are made to *break joint* with each other. Some iron ships are built without a keel.

In wooden and *composite* ships the keel is, as before stated, a rectangular piece of timber, and usually of equal or nearly equal *siding* and *moulding.* In large vessels the siding of the keel for about one-sixth or an eighth of its length at each end is often tapered at the rate of one-eighth of an inch to a foot, or thereabouts, at each side.

The scarphs of the different lengths may be either *horizontal* or *vertical*—the latter, however, being the stronger (fig. 10 is a *vertical* tabled scarph).

The length of a scarph should be at least *three* times the "moulding" or depth of the keel.*

Wooden ships are sometimes built upon a *temporary keel* of inferior timber to save the permanent keel from risk of decay. In this case the temporary keel has to be removed piece by piece, and the permanent keel fitted in its place after the framework has been built, and before the planking next the keel is permanently fastened.

A wooden keel has in each side a triangular groove or *rabbet* to receive the edge of the planking. There are two modes of forming this rabbet: both are shown in fig. 11. The old method is shown on the left-hand side of the sketch, the rabbet being marked *abc,* leaving a depth *cd* below the plank. At the present day the rabbet is brought to the lower part of the keel *f,* the lower part of the rabbet being only 4 inches from *e* (or *fe,* equal to 4 inches); the rabbet on

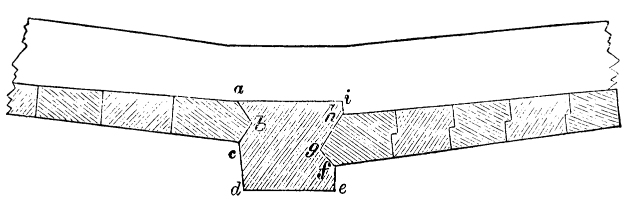


FIG. 11.

the lower side, or *fg,* is taken out in the same way as *cb* in the old system; but the depth, *fh,* is increased, so that *h* may be within 1½

* The scarphs of the "Merrimac's" keel were 9½ feet from lip to lip.

inches or 2 inches of the upper side of the keel, as *ih*; and the rabbet is then formed to the figure of which *hgf* is a section.

This formation of the rabbet admits of a thick plank being worked next the keel as a *garboard strake*, and in fact these several planks forming the garboard strakes may be denominated a combination of keel-pieces, adding greatly to the strength of the ship. Strength, however, is not the only advantage given by this mode of working the garboard planks.

In the old plan the depth of the keel, *cd*, below the rabbet, *abc*, formed a lever, and if the vessel took the ground, assisted materially in tearing the keel out of its place.

In the modern system the distance *fe* is not more than a quarter of the distance *cd*, which diminishes the leverage by $\frac{3}{4}$ of its length; while, in addition to this, the *extra* thickness of the garboard planks gives greater resistance to any movement of the keel either laterally or longitudinally.

To increase weatherliness and give the keel a firmer hold upon the water, its depth is increased by adding a *false keel* below it of the same siding as the main keel.

The pieces of the false keel are in a large ship from four to six inches in depth; they are scarphed in the same way as the pieces of the main keel; the *butts* or ends of each piece being placed between the scarphs of the main keel, so as to give greater strength to the combination. The false keel should be so fastened that it may be knocked off without injury to the main keel in case the vessel runs aground.

For weatherliness, both wooden and iron ships are sometimes furnished with *bilge* keels. The English iron-clad "Warrior" has several of these.

The depth of a wooden keel is sometimes increased at the top by adding to it a piece of *deadwood* of the same siding with the keel, and of depth sufficient to admit of the floor timbers being notched or scored upon it. The scarphs of the *deadwood* should *shift* or *break joint* with those of the keel.

The *stem*, which forms a continuation of the keel forward, is made of the same material, and is curved upward so as to form the extreme forward end of the ship. In wooden and composite ships it is scarphed, and in iron ships welded to the keel.

The stem of a large wooden ship may be composed of three pieces, known as the *upper*, *middle* and *lower* pieces. They should be scarphed together and united to the keel by what is known as the boxing scarph.

The stem of a wooden ship is sided at the lower end the same as the keel; but it is usual to make the siding enlarge gradually upward, until at the upper end it is about one-third part greater than at the lower end. The object of this is to give a broad enough bed for the bowsprit to rest on.

The stem has a rabbet taken out of it to receive the forward edges of all the planks known as the *hooding ends.*

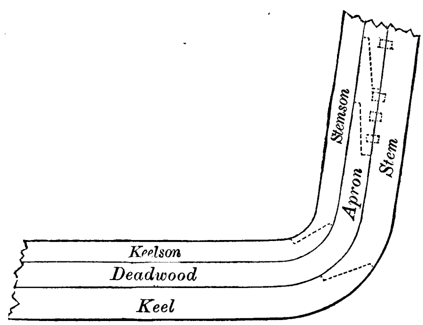


FIG. 12.

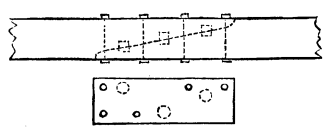


FIG. 13.

Figs. 12 and 13 represent the stem and boxing scarphs of the several pieces—O representing the *coaks* or *dowels* in the scarph; o the bolts, usually of copper.

An iron stem is usually a flat bar of uniform or nearly uniform siding. It has sometimes been made with a rabbet at each side to receive the foremost edge, or "*hooding ends,*" of the outside plating; but this is now rarely practiced.

The stern-post, or after boundary of the ship, is a straight piece of timber, vertical or slightly raking, which rises from the after end of the keel.

In a wooden ship it stands upon the keel, K (fig. 14), into which it is mortised by means of two tenons, each about *one-third* of the siding and *one-fifth* the moulding of the stern-post. The keel and stern-post are further connected by means of a pair of metal *dove-*

tail plates, DT. Immediately before the stern-post is the *inner stern-post*, I, of the same siding as the stern-post.

The stern-post in a wooden ship is usually of oak, and should be in one piece, if possible, of sound quality and well seasoned. Sometimes in large vessels a false post is worked at the after part of the main post; but such conversion should be avoided, if possible, as the rudder is hung to the post, which therefore should be as solid as possible. Should it be impossible to obtain the main-post of a large ship in one, it will answer to have the lower end scarphed, placing the outer butt of the scarph under one of the braces worked on the post for the *pintle* of the rudder.

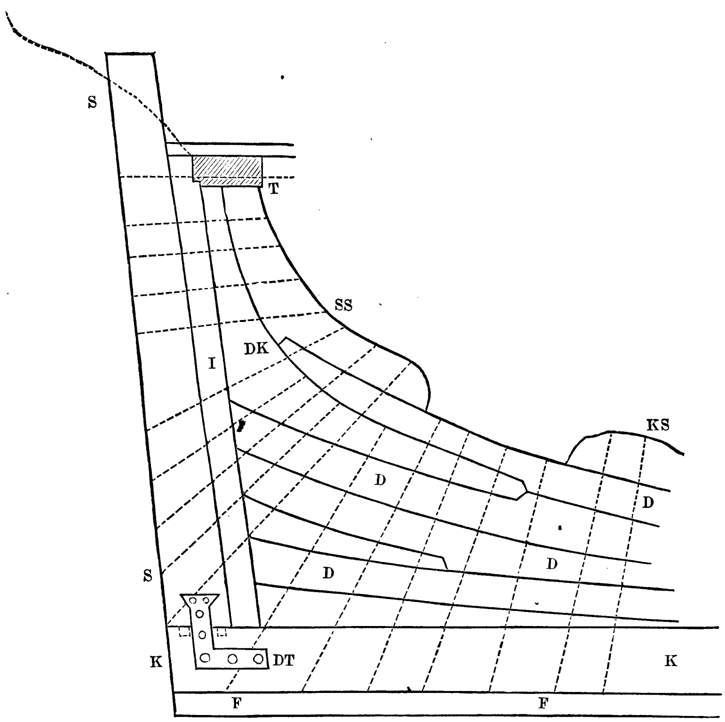


FIG. 14.

In round and elliptical sterns, timbers called *post timbers* are worked on each side of the stern-post to form the rake and contour of the stern; but it is advantageous to speed and steering that the

after edges of the stern-post should be *bearded,* so as to form a continuation of the curved surface of the vessel's run.

In an *iron ship,* the stern-post and after end of the keel are forged in one piece, which is scarphed or welded to the next piece of the keel. In a screw steamer, the forward or main-post or *propeller-post,* the after stern-post or *rudder-post,* the after end of the keel, and the *connecting piece* between the tops of the two stern-posts (forming together the frame of the screw-port), should be forged in one piece.

The main stern-post, in this case, is made about twice as strong as in other vessels of the same size; and a ring is forged in it at a suitable height for the passage of the propeller shaft. When the screw is made to lift out of the water, the connecting piece forms a ring of such dimensions as to allow the screw, with its blades erect, to be lifted through it.

The keel being laid on the blocks is prevented from shifting sideways by *nogs* driven into the blocks on each side of it; the stem and stern-posts are then set up in their proper positions, in a truly vertical, fore-and-aft plane; they are supported in that position by *shores* or props, and scarphed to the keel.

CHAPTER VII.

TIMBERS OF THE FRAME—HOW WORKED AND RAISED IN WOODEN SHIPS—FRAMES OF IRON VESSELS.

THE *frame* of a ship, sometimes termed the *ribs*, may be likened, not inaptly, to that portion of the human body which bears the same title. It is, in general terms, that portion of the whole structure which gives *shape* to the ship.

A wooden frame, however, is an *assemblage* built of two layers of pieces of timber, side by side, and breaking joint with each other, so that each *abutment*, *butt* or joint of one layer may be opposite the middle of a piece of the other layer. The pieces are called *floors* or *floor timbers, cross timbers, half floors, first futtocks, second, third, fourth* and sometimes *fifth futtocks, lengthening pieces*, and *long* and *short top-timbers.*

The upper and lower end of each piece is called its *head* and *heel.*

A *floor* is a piece that lies across and is bolted to the keel, and has a long arm on each side. It is *middle-seated* on the keel, by which arrangement the two arms of the floor timber reach equally on each side of the keel. *abcd* (fig. 15) is a section of the floor timber, *ef* being the middle line of the ship. This mode is usual in this country.

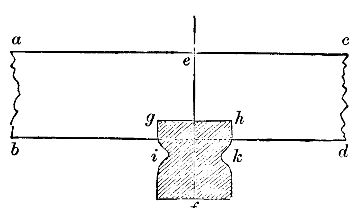


FIG. 15.

To give solidity to the floor when placed across the keel (technically called *crossing* it), a piece called the *rising wood* is worked, of which *gihk* in fig. 15 shows a section.

A corresponding *mortise* to fit this rising wood is taken out of the

seat of the floor, the double score being sufficiently deep to ensure the points i and k of the timber when let down being brought well to the upper edge of the rabbet of the keel, at i and k, so that the plank may lie on the timber and the edge of it fill the rabbet. In some instances the rising wood is dispensed with, and the floor has for solidity a coak, ×, placed in the seating, partly in the floor and partly in the keel (fig. 16).

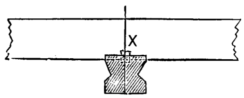


FIG. 16.

The usual practice is to have $1\frac{1}{2}$ inches of the wood of the keel above the rabbet, to do which $\frac{3}{4}$ of an inch is taken out of the keel, and the seating of the floor reduced also, bringing the lower side of the floor timber down to the upper edge of the rabbet of the keel, thus seating the floor on the keel with $\frac{3}{4}$ of an inch of wood to steady it. The floors are let down by what is called the *cutting-down staff*, from the mould-loft floor, which gives the height of the upper side of the *throat* of the floor at each frame. Some adopt the practice of having what is termed *a seating-line "razed"* on the keel each side, as a standard to measure from, to the seating of each floor on the rising wood.

A *cross piece* lies across and is bolted to the keel, having two short arms.

Half floors, used in connection with cross pieces, are pieces of timber abutting against each other on the top of the keel, each one being of the same length as an arm of a floor.

The method of uniting the two sides of the frame by cross pieces and half floors was introduced into practice by Sir Robert Seppings of the British Navy. It is a plan combining strength with economy, and has been extensively used—particularly in England. Fig. 17 will describe this method.

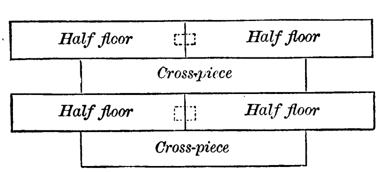


FIG. 17.

The butts of the half floors should be 2 inches alternately on either side of the middle line, in order to give a better space for placing the coak or dowel, which ties them to the keelson. To secure the half floors to the cross piece, and to make the three timbers in their combination

nearly equivalent to a solid mass, dowels or circular coaks are used of 3 inches diameter and length, sunk $1\frac{1}{2}$ inches into the cross piece or half floor, placed as shown in fig. 18.

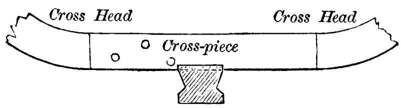


FIG. 18.

These dowels or tenons prevent the surfaces of the cross piece and half floors from sliding over each other, while the bolts placed in each arm of the cross pieces through the half floors effectually prevent a separation.

Still another method of uniting the frame, where timber is scant, is to have what is termed a *long and short armed filling-floor.* This is shown fully in figs. 19 and 20.

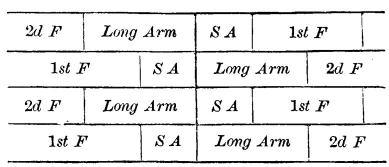


FIG. 19.

Suppose *abcd* (fig. 20) to be the length of the floor described in the first section on floors, a half shift or butt is adopted on one side as pointed out by the full line, *ef*, while the ticked line, *gh*, is the corresponding butt on the other side, giving two timbers at the middle line. This certainly assists conversion when all the lower timbers of the frame cross the keel; but such is not always the case, only one-half being so designed. The difficulty in obtaining half the lower timbers of this form, combined with the required conversion of the floors for the other half, prove that the system is attended with an increase of expense, while it has not a commensurate advantage in strength.

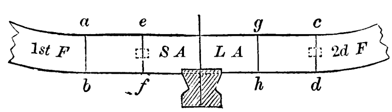


FIG. 20.

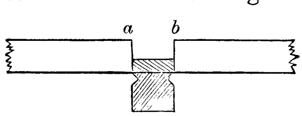


FIG. 21.

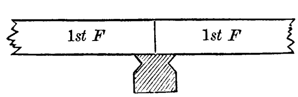


FIG. 22.

The timbers, called first futtocks, sometimes run down to the side of the *rising-wood* or *deadwood*, leaving a water-course, *ab* the breadth

of the keel: see fig. 21. Occasionally, also, they *butt* against each other at the middle line, as shown in fig. 22.

When cross pieces or long and short armed floors are used, they come to the heads of the cross pieces or floors; and dowels or tenons of hard wood are placed in the heads and heels.

The second futtocks are placed on the heads of the half floors, and the third futtocks on the heads of the first futtocks, the fourth futtocks on the heads of the second futtocks, the fifth futtocks on the heads of the third, and the top timbers on the heads of the fourth futtocks; these, with extra top timbers and lengthening timbers, complete the frame of a large ship.

In fig. 23, K is the keel, FK the false keel, D the deadwood, KS

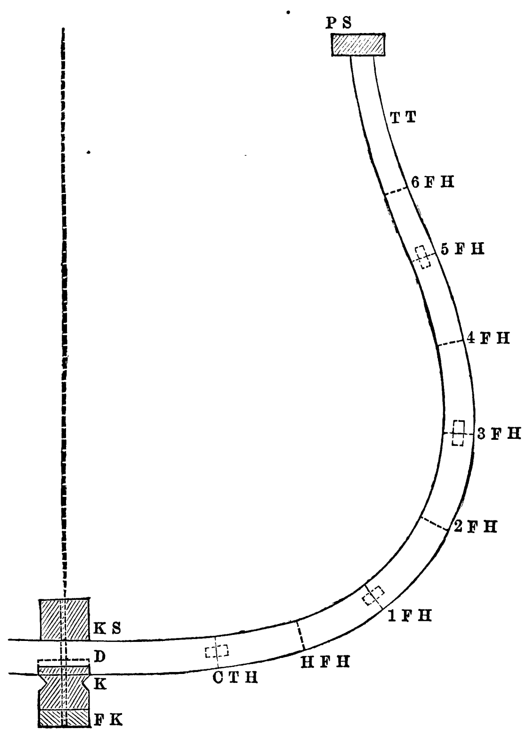


FIG. 23.

the keelson, CTH a cross-timber head, HFH a half floor head, 1 FH the first futtock-head, 2 FH the second futtock-head, etc., TT the

top-timber head, PS the *planksheer* (or *gunwale* as the case may be) morticed on the top-timber heads, and projecting outside and inside so as to cover, and sometimes slightly overhang, both the outer and the inner skin. When a pair of long and short armed floors are used instead of a cross timber, and a pair of half floors, CTH may be taken to represent the head of a short arm, and HFH that of a long arm.

The *frames* or transverse ribs in an *iron ship* are of an L-shaped, Z-shaped, T-shaped, I-shaped or trough-shaped section. One angle-iron is generally continuous for the whole length of the frame, the lengths of which it is made being welded together. The *floor* of an iron ship has usually two flanges connected by a *vertical web;* but in some instances the flanges have been connected by diagonal bracing instead of a web. The depth of the floors throughout the midship portion of the length of the vessel is regulated by considerations as to strength. In the fine parts near the ends of the vessel, which in a wooden ship would be occupied by deadwood, the *floor-plates* or web are triangular and rise to the height of the *cutting-down line.*

The distance that the frames should be apart requires careful consideration on the part of the builder as well as the architect, since this point has great influence upon the strength of the hull, as well as its weight.

The aim should always be to have the weight of the hull the least possible consistent with the required strength and firmness of fabric.

Room-and-space varies from 2 feet 6 inches to 3 feet 9 inches in wooden ships, and is marked off on the *tread of the keel* by a long measuring rod called a *room-and-space staff,* furnished from the mould-loft.

These *stations* being marked off on the keel, the joint of the *cross piece* with the *half floor,* or of the *floor* with the *first futtock,* is kept well to its *station,* and the frame timbers when raised are kept apart according to their respective sidings or thicknesses, leaving at all points the same room and space as at the keel.

The extremes of the ship, or the forward and after ends, have a form given to them that causes the floor timbers gradually to become more rising or V-like in appearance, and renders them difficult to be obtained, as not within the natural growth of timber. It is

therefore necessary to have recourse to other methods in order to continue the assemblage of timbers which compose the frame of a ship. That point in the length of the frame, where it would be advisable that the frame timbers should be reduced by the floor, must be determined by the builder with reference to the store of timber, the half floor and the second futtock of the *square body* being in the *cant bodies* cut in one length, and hence called *double futtocks.* After having fixed that point, the deadwood becomes the foundation, against which the heels of the double futtocks and first futtocks are abutted. The deadwood is worked of the same width as the keel amidships, and the keel tapering at the fore and after ends, the line of the upper edge of the rabbet rises up the deadwood to give the same breadth where the timber meets the deadwood, thus forming what is termed a *bearding* or *stepping* line.

Within the stem, to strengthen it and afford wood for the reception of the *plank of the bottom* and the heels of the *forward cant* timbers, a piece called the *apron* is worked. The *apron* is in reality a part of the forward deadwood, and its size is the same in the *sided* or athwartship direction as that of the *stem.*

In large ships it is composed of two pieces scarphed together, the scarphs *giving shift* to the scarphs of the stem. (Fig. 37.)

The scarphs of the apron are doweled and bolted together at the *lips* or ends, the middle of the scarphs being left for the bolts of the stem and of the *knee of the head* to pass through. The apron is also doweled to the stem, as shown in fig. 12.

As a further support to the stem, a timber called the stemson is worked. (Figs. 12 and 37.)

The cutting down of a floor is the height of its *throat* from the lower edge of the rabbet of the keel, as in fig. 24, where *ef* is the *cutting down* of the *midship floor.*

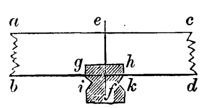


Fig. 24.

The moulding usually given to the midship floor is 1½ times its siding or thickness; and to determine the height of the cutting down of the forward and after floors, the scantling or size of the timber delineated to its full size on the mould-loft floor must be taken into consideration.

In the forward floor (fig. 25), *ge* is the form of the floor to the outside of the timber, as shown on the mould-loft floor, *ab* the form

given to the inside of the timber ensuring the *scantling* or size *ag*, while *af* is the height of the cutting down for the foremost floor. In the same manner the height of the cutting down, *cd*, for the after floor is determined so as to obtain the square scantling, *hc*. A batten passed through these three points—viz., the midship one, and the two fixed as above described—will give the height of the cutting down for all the floors, and if continued beyond these points to the stem and stern-post, will form the height of deadwood necessary for the reception of the heels of the fore and after timbers of the cant bodies.

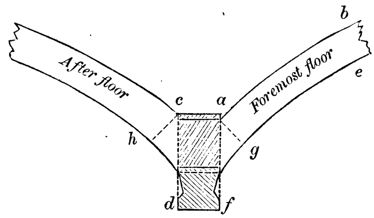


FIG. 25.

The *raising of the frames* in a wooden vessel is commenced by fastening together each pair of floors or of half floors with their

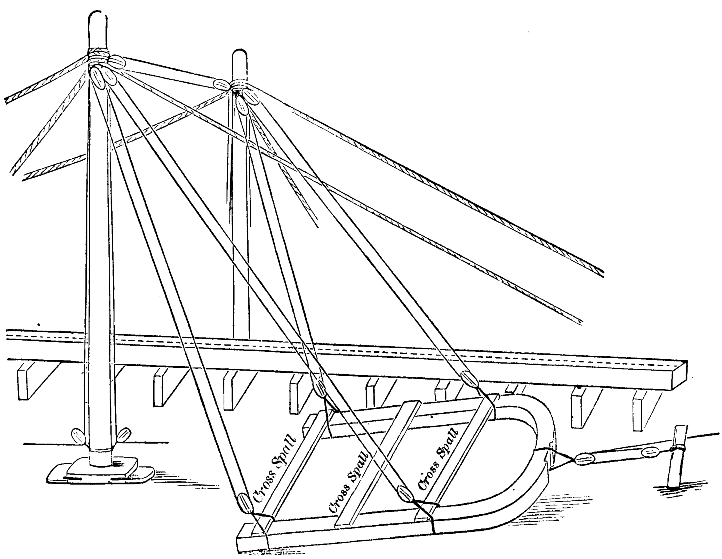


FIG. 26.

cross-timbers, bringing them to their *stations* razed on the keel and *crossing* them; that is, placing them perpendicular to the keel, and at the same time adjusting the scoring down of the deadwood, and if

necessary, trimming the floor timbers, so as to bring their upper surfaces exactly to the level of the cutting-down line, as furnished from the mould-loft by means of the *cutting-down staff*, on which are marked the heights of the cutting-down line above the keel at the several frames.

The pieces of each side frame, having been fastened together, are brought to their station, set up and fastened to the floors, or the whole frame may be united on the ground and then placed as in fig. 26.

They are hoisted into position by means of *sheers*, the curvature of the frame being carefully preserved as pointed out in figs. 27 (*a*) and 27 (*b*), each frame being set perpendicular by a level or plumb-line, and by a long straight batten placed from arm to arm of the floor or half floor at a given mark or station.

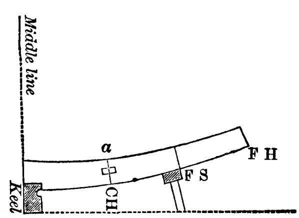


FIG. 27 (*a*).

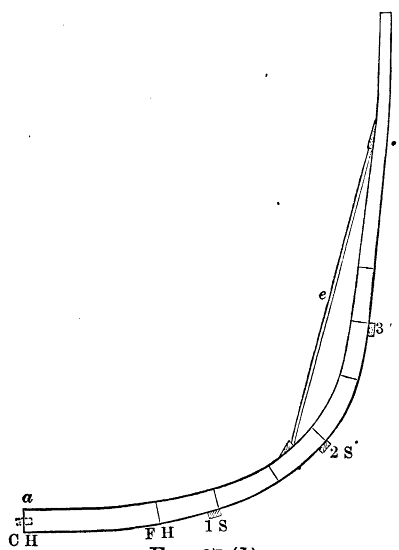


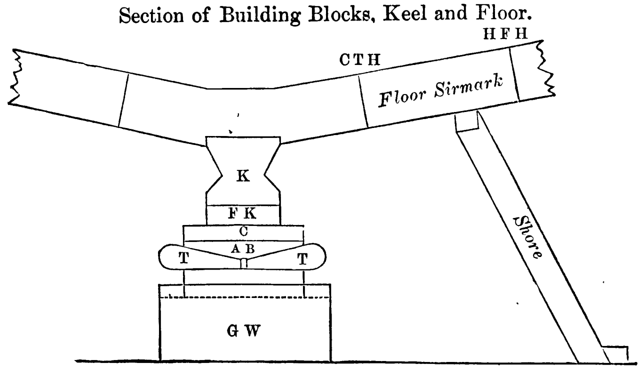
FIG. 27 (*b*).

Each frame is kept in shape by temporary timber braces; those which run horizontally being called *cross-spalls* (see fig. 26); those which run diagonally and vertically, *shores*. The cross-spalls are nearly in the position to be afterward occupied by the *deck beams*. The frames are kept in their proper positions by temporary wooden supports of the following kind:

Along each of the *ribband-lines*, outside of the frame, runs a long

piece of timber several inches square, called a *ribband* where it crosses the *square* frames, and a *harpin* where it crosses the *cant* frames; and at the *sirmarks* where the ribbands and harpins cross the frames they are attached to them with temporary iron bolts or screws. The ribbands and harpins are propped from the outside with sloping

Section of Building Blocks, Keel and Floor.



K, keel. FK, false keel. C, capblock. AB, angle-blocks. T, templates.

FIG. 28.

timber shores abutting in an open slip against stakes driven into the ground, and in a dock against the masonry of its sides. (Fig. 28.)

The timbers of a frame are connected lengthwise at the timber-

Section of the Timbers, showing the Dowel.

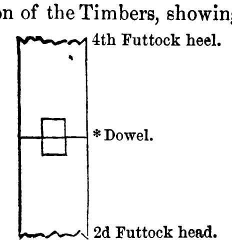


FIG. 29.

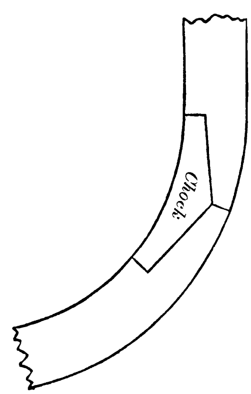


FIG. 30.

head in two different ways, by *coaks* or *dowels* (small cylindrical blocks of hard wood) fitting into holes in the heads and heels of the

timbers, as shown in fig. 29, or by *chocks* of an obtuse wedge shape, scarphed to the heads and heels of the timbers, as shown in fig. 30.

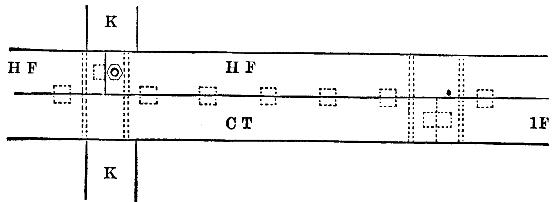
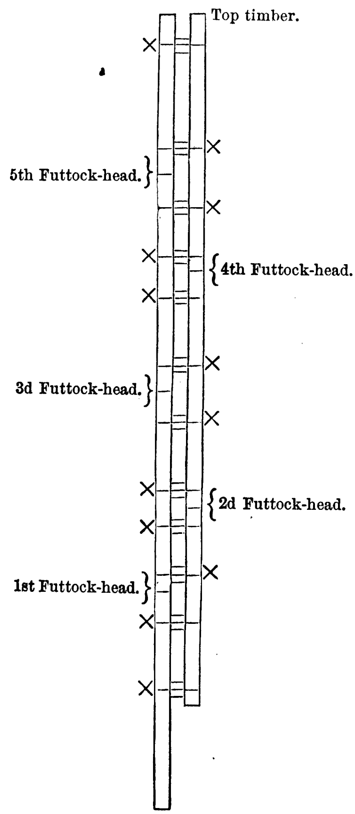


FIG. 31.

The dowels are 3 inches long, thus projecting 1½ inches into each timber. The chocks are said to cause an early decay of the frames, and are therefore not much used.



Frame bolts and chocks marked ×.

FIG. 32.

The timbers of a frame are connected together sideways by bolts near the head and heel of each timber, and also by coaks, spaced to about 1½ times the moulding of the frame. The position of such bolts and coaks is shown in fig. 31 (a horizontal plan), where KK is the keel, CT a cross timber, HF half floor, and 1F a first futtock.

In the lower part of each frame, from the keel to the floor-heads, and sometimes as far as the first or second futtock-heads, the two layers of timbers of which the frame consists usually stand in close contact, forming a seam, which is caulked. Higher up, there is often a narrow opening for the circulation of air; the timbers being kept at their proper distance asunder by the chocks or coaks, while they are held together by means of the *frame-bolts*. (See fig. 32.)

When the spaces between the

timbers of the hold are left open, *limber-holes* are bored through the frames of the floor and bilges for the passage of water; but in most men-of-war and in many merchant vessels the spaces between the floors and futtocks are filled in solid with *filling timber,* and the *seams* caulked.

In *iron ships,* whole frames are often raised as one piece.

Wooden ships are frequently left "*in frame*" to season—from six months to a year—before any *planking* is put on.

CHAPTER VIII.

TIMBERS OF THE FRAME, CANT BODIES, ETC.

A SHIP is generally spoken of as divided into fore and after bodies, and these combined constitute the whole of the ship. They are supposed to be separated by an imaginary athwartship section at the widest part of the ship, called the midship section or dead-flat.

The midship body is a term applied to an indefinite length of the middle part of the ship longitudinally, including a portion of the fore body and of the after body. It is not necessarily parallel or of the same form its whole length.

Those portions of the ship which are termed *square* and *cant* bodies may be considered as sub-divisions of the fore and aft bodies. There is a square fore body and a square after body toward the middle of the ship, and a cant fore body and a cant after body at the two ends. In the square body the sides of the frames are square to the line of the keel, and are athwartship vertical planes. In the cant bodies the sides of the frames are not square to the line of the keel, but are inclined aft in the fore body and forward in the after body. The reason for the frames in these portions of a wooden ship being canted is, that in these parts of the ship the timber would be too much cut away on account of the fineness of the angle formed between an athwartship plane and the outline or water-lines of the ship. The timber is therefore turned partially around till the outside face coincides nearly with the desired outline, and it is by this movement that the side of a frame in the cant fore body is made to point aft, and in the cant aft body to point forward. This will be best understood by the annexed figure, 33, showing an exaggerated horizontal section of a frame in the fore cant body, the dotted line representing the extent to which the timber would have been cut away if it had been placed

square to the line of the keel, and if the side *ab* had not been "canted aft," turning on the point or edge *a*.

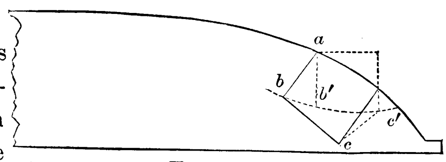


FIG. 33.

Now, as the cant timbers have gradually to be inclined forward 90° from the forward frame of the square body until they meet the stem, the heels of these timbers have a reduced space for their reception, and must be narrowed in their siding, in order that they may angle against each other and form close joints.

In fig. 34 let *ab* represent the forward square frame as it would be shown on the half-breadth plan; the heels must rest upon the line *af*, which gives less space than in the square body; consequently at *gh* two of the timbers will cross *de* at some point, as *l*; therefore the siding of each must be reduced correspondingly, that the joint may be close.

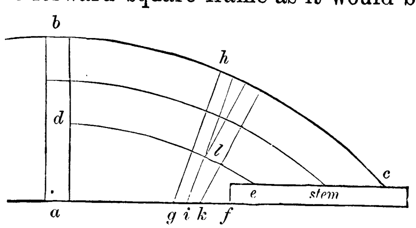


FIG. 34.

The lower part of a *cant frame*, or of a square frame which has a sharp *rise* of floor, consists of a pair of half floors springing from a pair of rabbets in the deadwood, or from a pair of *stepping pieces* bolted to the sides of the deadwood; which half floors are connected together across the top of the deadwood by means of a *cross piece* of suitable shape and dimensions. For example in the cross section, fig. 35, K is the keel, FK the false keel, D the deadwood, SP, SP stepping pieces, HF, HF half floors, KS the keelson, and the cross piece is shown by the dotted lines CP.

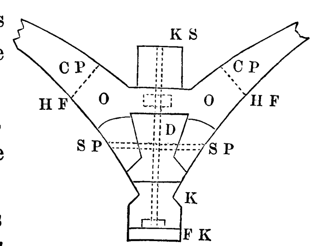


FIG. 35.

Against the stem, on each side, it is sometimes necessary to work *snaped* timbers called *stem pieces*, for the purpose of increasing the distance between the *knight-heads*, or first cant timbers on each side of the stem. This is to avoid cutting away

the knight-heads to form the hole for the bowsprit. The bowsprit is secured from moving sideways where it rests on top of the stem by means of the knight-heads KK in fig. 36, which generally stand (unless there are stem pieces) close to and on each side of the stem and apron, inside of the outside planking. The bowsprit hole, B, has its bottom formed by the top of the stem S, and apron; its sides by the knight-heads, and its top by blocks of wood called *bowsprit chocks,* filling the space between the tops of the knight-heads. Round the rim of the bowsprit hole is a square or oblong projection called the *boxing,* left on the knight-heads and bowsprit chocks, of depth equal to the thickness of, and forming the outside planking.

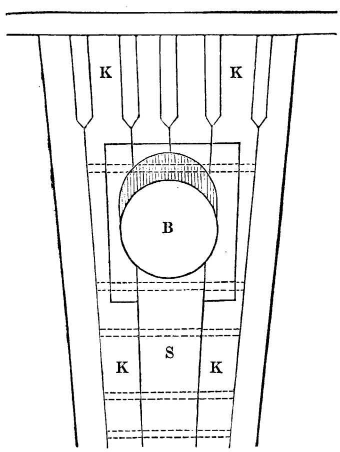


FIG. 36.

The *hawse pieces* are the cant frames on each side of the knight-heads to the number of six or seven; they are fitted close together so as to form a solid mass of timber for the reception of the four iron castings forming the hawse-holes.

In an *iron ship* the hawse-holes are cast-iron tubes, having a strong projecting rounded rim inside and outside; while the bowsprit hole is an iron tube supported at the ends by two thwartship bulkheads.

The following cut (fig. 37) will show the different timbers which compose the stem and *knee of the head.*

K is the forward end of the keel, curving upward slightly, and scarphed to S the stem: A is the apron, D the deadwood, consisting of pieces built up so as to fill the space between the planking and timbers of the sides of the bow, wherever that space is not wider than the siding of the keel.

SS, the stemson, being a continuation of the keelson, forward and upward, as the stem is a continuation of the keel.

DH, *deck hooks,* being thwartship frames crossing the apron in a

nearly horizontal position, to strengthen the bow and support the forward ends of the decks.

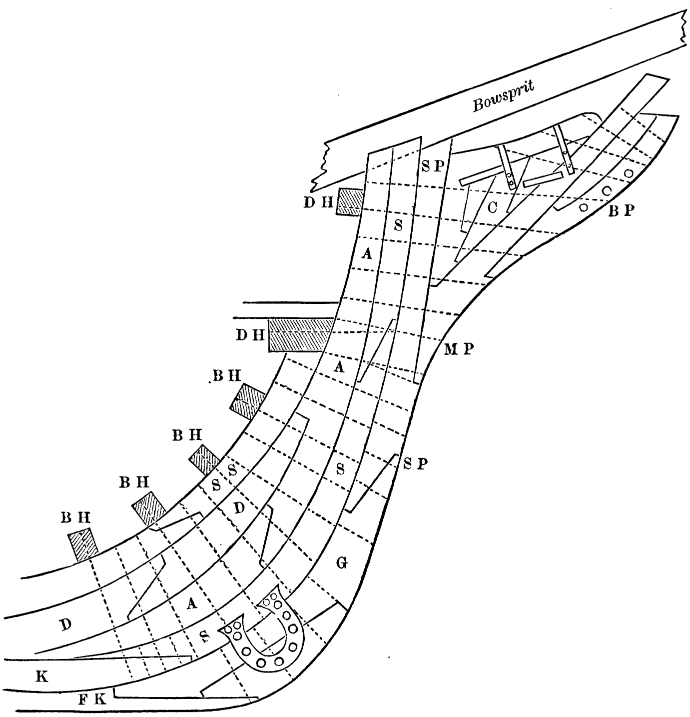


Fig. 37.

BH, *breast hooks,* to strengthen the bow—made either of wood or iron.

The following pieces compose the *knee of the head,* which is an addition to the moulding of the stem at its forward side, and serves partly as an ornament, partly for securing the bowsprit and its rigging.

SP, the *independent piece;* MP, the *main* or *lace piece*; BP, the *bobstay piece;* C, the *chocks* or blocks to fill up the required shape of the head. The two holes are for the iron *gammoning,* and are called *scuttles.*

The keel, stem, apron, deadwood, stemson and pieces of the head are so arranged that their scarphs break joint, and after being coaked

are bolted together by bolts arranged in the manner shown by the dotted lines; so that all the pieces of timber may act as far as possible like one piece. The lower side pieces of the head are called *cheeks*, and the upper, *head-rails*.

To give the vessel a good hold of the water, and so promote weatherliness, the *gripe*, G, is fastened upon the lower part of the stem by the aid of a pair of pieces of metal called *horse-shoes*, as shown in fig. 37. The *gripe* forms a sort of continuation of the false keel FK, and should be so fastened that it may be knocked off without damaging the stem.

It is favorable to speed to have the forward edges of the stem and gripe, bearded or beveled so as to form a continuation of the curved surface of the ship.

The sterns of ships have a variety of figures, depending more on taste and fashion than on principle and practical utility.

The *square* stern is the oldest form, and is still in use in the merchant service; there is also the *round* and the *elliptical* stern, used in iron merchant vessels and in iron and wooden men-of-war.

The *counter* of the ship is that part which overhangs the stern-post. The head of the stern-post rises into the interior of the ship a short distance above the counter; and immediately abaft it is the *rudder-port*, being a hole in the counter for the passage of the rudder-head. The rudder-head, and the rudder-port which it nearly fits, are cylindrical, the axis of the rudder being the axis of motion, and in one straight line with the axis of the pintles and braces by which the rudder is hinged to the stern-post; while the head of the stern-post is formed so as to admit of the rudder-head having a diameter sufficient for strength.

In an *iron ship* the stern framing may be constructed in the following manner: The stern-post, at its head, may branch out into two ribs, forming a frame, like the other frames of the vessel. It is advisable that this frame should be either wholly or partially filled by a plate-iron bulkhead, with such openings in it as may be necessary for the passage of the tiller or for other purposes. Then from that frame may spring *counter-frames*, each rising in a longitudinal or slightly oblique plane, having the same room and space, or nearly so, as the frames of the ship's body, and projecting out astern in such a figure as the designer may choose.

In a *wooden ship* the stern framing sometimes begins at a pair of cant frames called *fashion-pieces* FP, FP (fig. 38). In the square stern the *wing-transom*, WT, extends across between the fashion-pieces, crossing in front of the stern-post, S, near its head. The wing-transom is nearly straight, having only a slight "*round aft;*" and it has also a "*round up,*" depending on the taste of the designer.

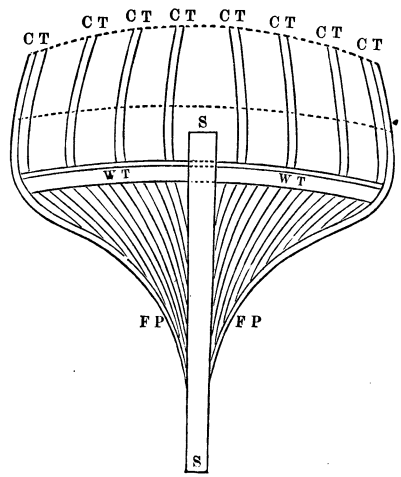


FIG. 38.

At the upper and after edge of the wing-transom is a projecting moulding called the *margin*, the under side of which forms a continuation of the after side of the rabbet of the stern-post, so that the hooding-ends of the planking of the *buttock* abut against it. Abaft the fashion-pieces, and below the wing-transom, the framing may consist either of a series of transoms bearing the same relation to the stern-post that *breast-hooks* do to the stem, or a series of radiating cant frames called *after timbers*, stepped partly on the dead-wood and partly on the *stepping pieces* bolted to the sides of the inner stern-post. The latter is the construction shown in fig. 38.

Above the wing-transom spring *counter-timbers*, CT, of such shapes as the designer may think fit. Their moulding planes are usually made to incline slightly inward; and it is considered conducive to an elegant appearance that their upper ends should converge toward one imaginary point. Between the counter-timbers are the stern windows, if any.

Along the upper ends of the counter-frames or counter-timbers runs the *taffrail.*

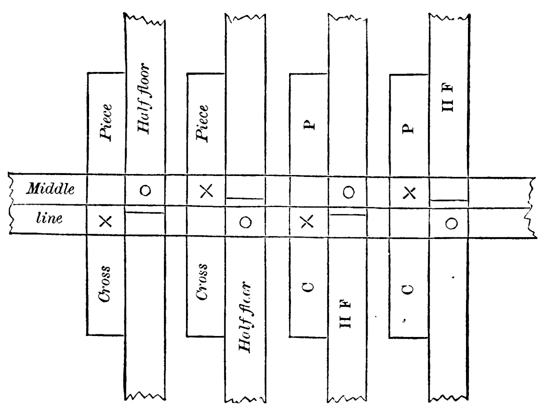
The framing of a round or an elliptical stern consists of cant frames in radiating planes, running the whole way up to the taffrail; and in iron ships this mode of framing is often used.

The counter-timbers are crossed inside by *deck-transoms* to sup-

port the decks, and outside by pieces called *stools* and *cornices*, which in the old wooden ships of the line were made to support one or more *galleries* or projecting balconies, accessible through the stern windows.

The keelson may be considered as an internal keel worked with the view of strengthening the vessel lengthways, and, in conjunction

Disposition of the Fastening in the Keelson.



O Coak or dowel. ✕ Bolt.

FIG. 39.

with the keel, confining the floors in their respective stations. The bolts of the keelson are driven through the *throat* of each floor and through the main keel. The keelson is generally coaked or doweled to the half floor or first futtock of each frame; and, for the better reception of these dowels, the half floors are not butted or joined at the middle line of the vessel (on the alternate sides) in order to assist in the disposal of the coaks (see fig. 33). The keelson, in scantling, is the square of the siding, or athwartship way of the keel, and in conversion the lengths are determined by a due regard to the store of timber and the shift necessary to the scarphs of the keel and the centres of the masts, while the foremost and aftermost pieces should extend beyond the floors of the square body, so as to connect the keelson with the deadwood.

In fig. 40, *gh* is the keelson, square in form and *sided* the width of

the keel, *kl*; *c* and *d* are the heads of the cross-pieces; *e* the *butts* of the half floors, placed on one side of the middle line to admit of a coak, *f*, being used clear of the butt.

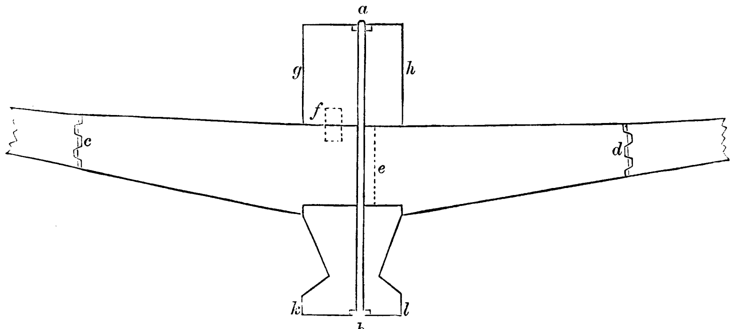


FIG. 40.

ab is the keelson bolt passing through the keelson, cross-piece and keel. This bolt should be placed, as in the figure, on one side of the middle line in order to give greater solidity to the combination—the limit to the *spread* of the keelson bolts being such that they may not *break out* in the rabbet of the keel.

Where the first futtocks do not come to the middle line of the vessel, dowels are dispensed with.

Keelson bolts are of copper, and vary in diameter, according to the tonnage of the vessel, from $1\frac{1}{2}$ inches to $\frac{7}{8}$ths of an inch. These bolts are driven on a ring of mixed metal, and the copper being beaten out by clinching, a head is formed larger than the ring, which gives a greater hold than the friction of the bolt. The tie to the keel is completed when the point of the bolt is clinched over a ring let into the under side of the main keel; and this arrangement of the fastening unites firmly the keelson and keel together through the medium of the cross-pieces and half floors. The rings are shown in the sketch at the head (*a*) and point (*b*) of the bolt (*ab*), fig. 40.

Water-courses should be formed under the keelson and side keelsons, which is effected by moulding the fillings smaller than the timbers. (See fig. 42 and description.)

Inside the frame of the ship, abreast the mainmast and about 6 feet on each side from the middle line of the ship, timbers called *side*

or *sister keelsons* are worked, in order to strengthen the ship in the

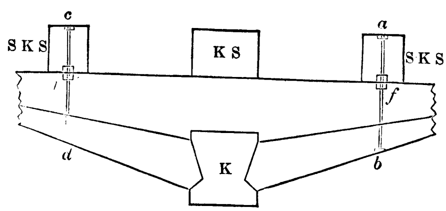


FIG. 41.

immediate vicinity of the mainmast, the step to receive the mast resting in part on these auxiliaries to the main keelson. The lengths of the side keelsons vary from 30 to 50 feet, according to the size of the ship. The siding and moulding of these timbers is usually 2 inches less than that given to the keelson itself; they are bolted with copper bolts through the timbers of the frame and the plank of the bottom, these bolts forming part of the fastening of the outside planking. In fig. 41 the relative positions of these keelsons are shown, *ab* and *cd* being the bolts, forming also a portion of the fastening of the bottom plank. The side keelsons are doweled to the timbers of the ship; the dowels, *ff*, being placed in such timbers as do not require a bolt. Their number is limited by their distance apart, which should be 6 or 8 feet.

REFERENCES TO THE MIDSHIP SECTION, FIG. 42 (*a* and *b*).

A, the thickness of the several decks or platforms: *vide* Scheme of Scantlings.

In small vessels the decks are named as follows: Spar deck and berth deck. In a frigate, where the guns range fore and aft the vessel, there is the spar deck (*i. e.*, poop, quarter deck, waist and forecastle), main deck, berth deck and sometimes orlop.

B, the beams placed across the ship to receive the platforms or decks.

C, waterways to receive the decks and hold down the ends of the beams (B).

D, shelf pieces at the several decks (A), to receive the ends of the beams (B), and form part of the security of the beams to the side of the ship.

E, iron knees, to further connect the beam (B) to the sides of the ship, and thereby unite the two sides firmly together. These knees may be considered as an increase in the breadth of the shelf (D), the required size of iron being much less clumsy than wood of equal

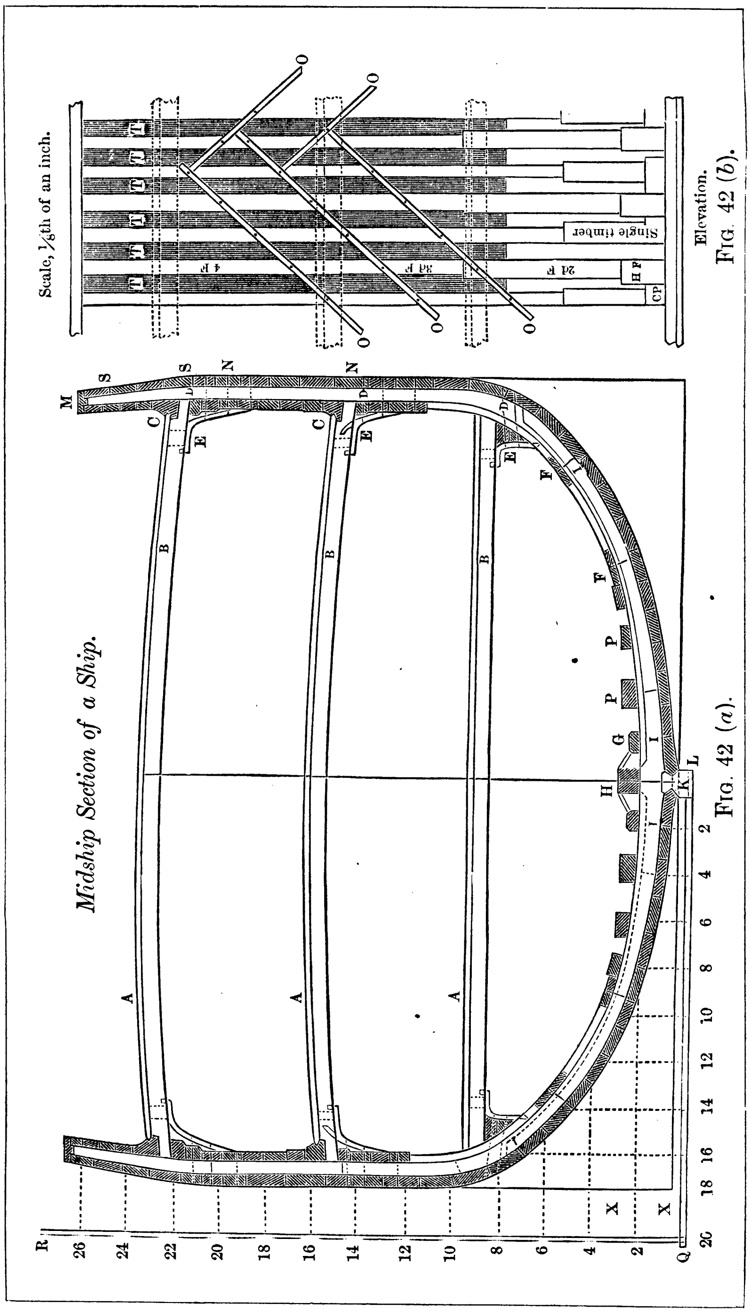


FIG. 42 (a).

FIG. 42 (b).

strength would be. The dotted lines through the side, and up and down each of the knees E, are the bolts which fasten them to the beam and side of the ship.

F, thick strakes of plank worked over the heads of the floor timbers and the heads of the first futtocks, to prevent the heads and heels of these timbers of the frame from being forced in. They are bolted to the timbers and outside planking by the fastening of the bottom plank.

G, limber strakes, to form a gutter leading to the pump well on each side of the keelson (H), that the bilge water may pass freely to the pumps, which are placed in the immediate vicinity of the mainmast.

The limber boards are shown by this section with one end on the keelson (H), and the other on the limber strake (G); these boards form a covering to the limbers to keep them from being choked with dirt. Sometimes the limbers are covered by iron castings forming part of the ballast required in the ship.

H, keelson, or internal keel, to confine, in conjunction with the keel (K), the floors of the frame of the ship in their places; the keelson bolts which pass through keelson, floor and keel are, in a first-rate ship, $1\frac{1}{2}$ inches in diameter.

I, fillings between the frames, being less than the moulding of the timbers by the distance the dotted line is below the full line of the section of the timbers, thus forming a water-course to the limbers.

K, section of the keel, showing the rabbet for the reception of the plank of the bottom.

L, section of the false keel, used to give depth of immersion to the vessel, and which, being slightly secured to the main keel, admits of being easily removed by a blow should the ship strike the ground.

M, the roughtree rail, forming the upper boundary of the timbers of the frame, as well as of the exterior and interior planking.

N, wales or thickest planking used on the outside of the ship.

O, iron diagonal braces, shown in the disposition of the frame. Their thickness and breadth are given in the Scheme of Scantlings; they are sometimes let into the timbers of the frame their whole thickness, at other times half the thickness; and the system has been adopted by some practical builders of bringing them to the timbers without letting them in at all. The question hinges on this: Which

is best for the strength of the ship—to score into the timbers only, to score into the timbers and internal planking equally, or to take the whole scoring out of the internal planking?

P, the boiler keelsons of a steam vessel, corresponding to the side keelsons of a sailing vessel. They are worked the length of the engine-room and 10 feet beyond at each end; they receive the boilers and bed-plates of the engines.

S, sheer strakes.

T, of the disposition, shows the room and space between the timbers of the frame marked by the shaded lines. These openings, as before remarked, should be equalized all the way up the frame to the highest point at the roughtree rail (M); the dotted lines show the height of decks. (Fig. 42, *b*.)

The thickness and breadth at each portion of the *wales*, *diminishing plank* and *plank of the bottom* are shown in the sectional view.*

* *Method used in taking the form of a ship when built.*—Many ships during war are captured from the enemy, of whose form no drawing is in the possession of the captors, while their good sailing qualities are such as to make them a desirable guide for naval construction; therefore such vessels should be placed in a dry-dock and their form taken by a draughtsman, a drawing upon the usual scale being made. The outline of the method pursued is shown, attached to the midship section of fig. 42 (*a*), and as the process for one section would carry the novice nearly through the whole operation, the description of one must suffice:

A base board (Q), or board having numeral feet marked on it, is placed against the side of the keel (K), this base board, as in the figure, being set by a spirit-level to the horizon, and square to the keel by a large square placed with one of its arms against the side of the keel, the base board (Q) being kept to the other. Another board (R, Q) is then fixed perpendicularly to this, as shown in the section, having also a graduated scale of feet marked on it. The distances at every 2 feet from these standards of measurement are then taken on the plumb or perpendicular, and the level or horizontal (as shown on the figure by the dotted lines), to where they meet the body of the ship or the wales, diminishing plank, bottom, etc.; these distances are registered in feet and inches, and set off on paper to the scale chosen for the drawing, when the form of the section cannot fail to be accurately depicted.

The perpendiculars marked X in the section form the boundary lines of the greatest transverse or midship section, and hence enclose all other sections taken by the same system. The forms of models may be taken in the same way.

CHAPTER IX.

STRENGTHENING THE FRAME—FILLING IN—DIAGONAL BRACING AND FASTENING.

In order to strengthen ships and make them perfectly water-tight, even though the outside plank may be knocked off, a system known as that of *filling in* was introduced into the practice of ship-building by the celebrated Sir Robert Seppings, a surveyor of the British Navy.

This consists in filling the openings between the timbers of the frame as high up as the air ports (or a few feet above the load-water line) with slips of slab timber; which being caulked and "*payed*" make the frame from stem to stern one compact and water-tight mass of timber, so that were any of the outer planking of the bottom to be knocked off, the ship would not only still keep afloat, but would be secured from sinking. In the old system, the starting of a plank would be, and often has been, fatal. The mode of filling in these openings between the frame, where the width of the space does not exceed three inches, is by driving in slices of wood cut wedge-like; two of which being driven, one from the outside, the other from within, form the paralleled space of the opening, thereby bringing the parts into the closest contact. In the openings exceeding the width of three inches, the space is occupied by pieces corresponding with the openings, the fibre of such pieces being laid in the same direction as that of the frame timbers.

These fillings occasion no consumption of useful timber, as one-fourth of the produce of slab and other offal wood would supply a sufficient quantity for the consumption of the whole navy.

The advantages obtained by filling in the openings are these:*

* H. B. M. ship "Orestes" struck upon a sunken rock on the coast of Portugal. By this accident *eighteen* feet of the main keel, from the mainmast forward, were knocked

To add to the strength and durability of the fabric; to preserve the health of the crew from the effects of the impure air arising from the filth which soon collects in these openings; to render the ship less liable to leakage, as well as to facilitate the stoppage of any leak; and lastly, to increase, as it may be said, the thickness of the bottom from four or four and a half (the usual thickness of the plank) to about sixteen inches, thereby lessening very considerably the danger to be apprehended from getting on shore or foundering at sea. That it tends also to the durability of the ship will be inferred from the following positions:

1st. That the openings in the old principle are, after a ship has had any considerable length of service, choked up in many parts with an accumulation of filth.

2dly. That no free circulation of air can be obtained in these openings by any means.

3dly. That timber being either freely exposed to or excluded from the air is equally preserved.

4thly. That it has been found, on examining the frame and plank of old ships, that those parts (now filled in) generally decay sooner than the rest—viz., from the floor-heads in the midships, and from the deadwood forward and abaft to the height of the orlop clamps.

The *filling* of spaces between the frames in *iron ships* is done with cement, brickwork and other materials. In *iron vessels* this is usually done after the *outer* skin has been put on. If cement is used, it should be carefully kept dry until wanted; its quality should be ascertained by mixing it with the proper proportion of sand (about half the bulk of the cement), and observing whether a specimen *sets* or hardens rapidly under water. The sand should be clean and sharp. Too much sand should not be added, as it makes the cement brittle. The cement should be used *at once*, and not left standing. Every part of *each space must be thoroughly filled with it;* and it should form a complete coating to the iron of not less than half an inch in thickness at the thinnest part.

Gas coke is sometimes used as well as brick. Brick should be of

off close up to the "garboard strake." During a passage of eight days, to Spithead, the ship made no more water than four *inches* per hour. Had the timbers of the "Orestes" not been "*filled in,*" the probability is, that the ship would never have reached port.

hard, regular figure and smooth surface, compact, and should give out a ringing sound when struck. Brick filling should be built in cement, as already described, and each brick should be soaked in water before being laid; otherwise it will dry the cement too fast and make it crumble.

Asphaltic mastic may also be used for filling, and can be made either by combining seven or eight parts of powdered natural asphalt in a boiler with one part of bitumen, at a heat sufficient to liquefy the asphalt, or by making an artificial asphalt of coal-tar mixed with finely-ground limestone or fire-clay, until a composition is obtained which, when cool, is just soft enough to yield visibly to the pressure of the nail. The asphaltic mastic may be mixed with one-half or three-fifths its volume of sand, and then used for filling, either alone or along with bricks, which, before being built, should be heated in an oven and dipped in coal-tar.

Sir Robert Seppings also introduced, as a substitute for a portion of the internal planking, a combination of wood-trussing to strengthen the ship, illustrating the intended effect by a reference to the stability given to a five-barred gate by the bar which is placed across the horizontal portion of it. The illustration would have held good had the strain been similar to that to which his trussed frame in the hold of the ship was subjected. In the gate, the stiffness being required in the vertical position, the cross-bar is effective; but the same gate would be found weak if its strength were tested by a force applied to bend it horizontally. This trussing frame, called by its projector *a diagonal frame*, was composed of timbers nearly equal in dimensions to the lower timbers of the ship, disposed diagonally or athwart the frame of the ship; but in the lower part, or near the keelson, this trussing, in flat-floored vessels, was wholly out of comparison with the vertical position of the bar of the gate; and in those ships having a *rising floor* it only approximated to it. The diagonal framing thus became nearly useless as a truss, and its only beneficial effects were to unite the several timbers of the frame together in a longitudinal direction. This framing was also found to interfere with the stowage in the hold, to be subject to early decay, the more especially so where old ship-timber was used for this purpose, as originally suggested by the projector; and, moreover, to yield little real strength to the ship. This result led to the introduction of the present mode of tying the

frame-timbers to each other by a succession of iron plates (fig. 42, *b*), as a substitute for the old wooden truss. These iron plates vary in size according to the rate or tonnage of the vessel, their thickness being from ¾ inch to 1½ inches, and their width from 3 inches to 6 inches; their lengths in some cases extending from within a short distance of the keelson to the top sides or upper part of the vessel.* The system is called *diagonal bracing.*

The mode of working these plates has been the subject of much controversy among practical builders. In some instances they have been bent to the inside of the timbers without being inserted into them; while in others they have been buried half their thickness in the frame timbers; and in some cases the practice has been to let them in to their whole thickness; but the insertion into the frame must be erroneous; the frame of a large ship is always difficult to obtain the moulding way; and the axiom of nothing being stronger than its weakest part should cause the practical builder to reflect well before he weakened the frame of his ship by the score necessary to receive a plate that has little tendency, when worked, beyond the stringing, as it were, of the timbers of that frame together. These plates are bolted through the frame-timbers and outside plank; and these bolts should form part of the regular fastening of the bottom. In small vessels the diagonal braces are screwed to the frame-timbers by short screws in the alternate holes; and it is advisable, in all vessels secured by this system, to work these iron braces (or riders) before the outside plank is brought to, securing them temporarily with screws; for the timbers of the frame being in some degree united by them, these plates will then prevent the *edge sets* used in planking from separating the heads and heels of the several assemblages of timber which constitute a frame and produce a desirable result; for, if such a separation takes place to any considerable extent, the stiffness of the frame is in a great degree destroyed, as the heads and heels of the several timbers can and will *work* over each other when the ship is acted on by the force of a heavy sea.

Fig. 42 (*b*) shows a portion of a diagonal frame of the present day.

* The iron plates or diagonal braces at the top sides should be reduced in thickness in the midship portion of the ship; while at the bows and quarters of the vessel, both upper and lower diagonals should be reduced both in thickness and width.

This system of framing entails a very great extra expense, and on that account another system, known as "Gordon's," was introduced into a number of merchant vessels with excellent results.

A system of wooden braces (or trusses) was placed between the lower and upper decks, where the ship is *straight of breadth* and *wall-sided.* The *body* of the ship was thus made rigid or immovable at that part, and the strength of the ends made to depend upon the strength and rigidity of the *middle body.*

Two English line-of-battle ships ("Trafalgar" and "Royal Albert") were braced in this way, and the result in each case was all that could be desired.

CHAPTER X.

THE SHELF, WALES AND PLANK OF BOTTOM—HOW WORKED AND FASTENED IN WOODEN SHIPS—PLATING AND FASTENING IRON VESSELS—DIFFERENT MODES OF CONSTRUCTING THE LATTER.

At the height of the under side of the beams on which rest the decks of the ship, internal ribs of wood are worked longitudinally the whole length of the vessel to receive the ends of the beams. These timbers are called *shelves,* and may be considered as portions of the internal planking of the frame. The shelf is usually *brought to* and worked, but not bolted, before the outside plank is brought to, thus forming a good internal *ribband* to preserve the form of the ship while the outside plank is being worked—Blake's screws being usually employed to keep it temporarily in position.

Fig. 43 shows the section of the frame-timber, *shelf* and beam as usually worked. The shelf is composed of several lengths or shifts, the one being scarphed to the other by *vertical scarphs,* the length of the scarphs being governed by their being made equal in extent to two portions of the room and space given to the timbers of the frame. The scarphs are coaked or doweled together with three dowels;

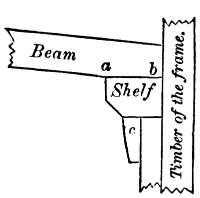


Fig. 43.

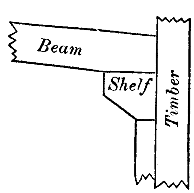


Fig. 44.

and on bolting the shelf one bolt is generally placed through it at each frame-timber, except forward and aft, where the distance between these bolts varies from 2 feet 6 inches to 3 feet. The upper

surface of the shelf *ab* (fig. 43), on which the beam end rests, should be below a level, to prevent a lodgment of water. Fig. 44 is a section showing another method used in working the shelf, which does away with the chock (*c*) necessary in the plan (fig. 43) to receive the iron knees that unite the ends of the beams to the sides of the ship. The bolts used for the shelf are of copper, varying in diameter from ¾ of an inch to 1¼ inches, according to the tonnage of the ship and the thickness of the body at the several portions of the ship where the shelf is worked. These bolts should form part of the regular fastening of the outside planking, and should be placed as nearly square to it as the nature of the work will admit; for it should be carefully kept in view that the shortest fastening through a given or fixed thickness is to be preferred, as embracing twofold advantages—that of strength, together with economy in the use of such an expensive material as copper. Moreover, a reduction of copper bolts in length, with no diminution in the fineness of the hull, is attended with the best possible result—the maximum lightness of the hull of the ship. To exemplify this, fig. 45 is given as descriptive of the lower shelf of most ships, the shelf lying oblique to the timber of the frame.

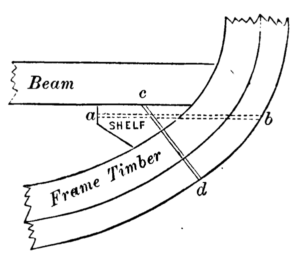


FIG. 45.

ab the usual level bolt, cutting the outside plank obliquely; *cd* the bolt placed square to the outside planking, shorter than *ab*, and square to the seating of the shelf on the timbers; hence a stronger, lighter and cheaper fastening.

The frame of a wooden ship when completed in the harpins and ribbands has the shelf worked as just described, after which the next step is to cover with plank.

In merchant ships, as well as in men-of-war, the position of the *wales* or *bends* (see N, fig. 42), is first *razed* on the timbers by means of long battens called *sheer battens;* the proper position for these lines having previously been determined on the building draft. It may here be observed that the builder's draft should not only show everything important in the ship, but also the relative positions of

the bolts, butts and fastenings, in order to avoid *over-fastening* or an increase of weight over that required.

The frame of the ship, previously to the plank being worked, should be set perpendicular by dropping a plumb-line from the centre of the *cross-spalls*. The point of the brass or plumb should agree with the middle line of the ship, razed upon the upper side of the keelson, but if it should not do so, the shores placed to the ribbands should be loosened on the one side and driven up on the other, until the point of the plumb touches the middle line.

The cross-spalls are long pieces of plank which have the breadth of the ship at particular stations marked on them, and they are secured to the timbers at their stations, to preserve the form of the ship while she remains *in frame*, and until the *beams* are crossed.

The *bends* or *wales* are usually of oak *thickstuff*, running from 4½ inches in thickness in small vessels to 10 inches in first-rates. A representation of the plank, or, as it is termed, *a shift of the butts of the plank*, should be made on paper by the draughtsman, who, in making it, must have cautious reference to the store of thickstuff and plank at the builder's command before he determines the lengths of the plank or shifts to be used in building the vessel. The ports in ships of war will require consideration when determining the *butts of the wales.** Some plank or thickstuff, from being cut out of trees wide at the lower end and narrow at the top, partakes of the character of the tree, and hence for economy and good conversion requires to be worked in a peculiar manner, denominated *top and butt*, which consists in bringing the butt of one plank to the top of the other, so as to make up a constant breadth in two layers, as shown in fig. 46.

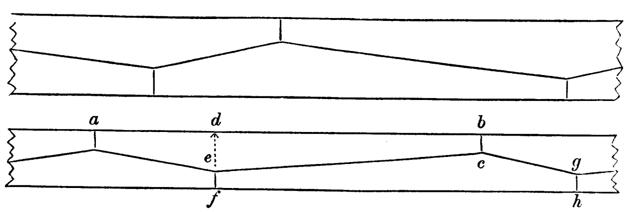


FIG. 46.

Thus in the two planks, *ab* and *fh* (the width of the two being 2

* With reference to having each plank or shift of the same length as the space occupied by several ports, hence called port-shifts.

feet), it is usual to work what is called *the touch* (*de*) 15 inches, leaving *the top* (*ef*) of the lower layer 9 inches, to complete the width of 24 inches, or, if it will assist conversion, these may be altered to 14 inches and 10 inches. The touch *e* is taken at one-fourth the whole length of the plank from the butt end. This arrangement makes the edge of every other plank a parallel or *fair edge.* Some oak plank and thickstuff is worked *anchor-stock* fashion, but this should be resorted to only in extreme cases, from the extravagance of the conversion; it may, however, be worked with advantage in the *channel wales* and *spirketing* of frigates.

Sketch of two Layers of Plank worked Anchor-Stock.

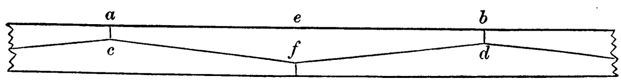


FIG. 47.

The thickstuff is *lined* for anchor-stock conversion by making it hold its greatest width in the middle of its length, as *ef,* while the width of the top, *ac,* determines the reduction to be made in the butt end (*bd*)—*bd* being made equal to *ac;* hence the points *c* and *f, d* and *f,* being joined, give the form of the plank, while the under layer, being of the same shape, makes the width of the two together that which would result from adding the breadth which the plank holds in the middle of its length to its width at the top end. This method gives a fair edge or line for every two layers of plank worked. From the lower edge of the wales, the width of which in very large ships extends to 14 strakes, the planks have to be diminished in thickness to meet the intended thickness for the plank of the bottom. Thus, in a ship where the wales are 10 inches in thickness and the bottom plank 5 inches, the planks following immediately under the wales have gradually to be reduced in thickness from 10 to 5 inches; the planks which are worked to effect this graduation in thickness being technically denominated *diminishing stuff;* while the method usually adopted to regulate the decrease is to strike two lines tapering as follows:

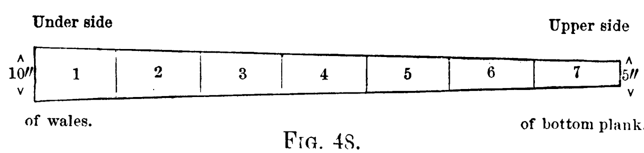


FIG. 48.

The diminishing plank, when of English oak, is worked top and butt for economy, hence each of the sections marked 1, 2, 3, etc., contains two layers of the depth, giving in this example 14 planks to effect the diminution from 10 to 5 inches, or nearly three-fourths of an inch difference between the upper and lower edges of every two consecutive planks worked on the top-and-butt system.

The plank of the bottom extends from the diminishing plank to within five or six strakes of the keel; the latter being of elm or oak, and termed *garboard strakes.* The plank of the bottom below the diminishing plank, as far as the supposed light draught of water, is usually of white oak, the remainder of the bottom being of yellow pine to the garboard strakes. In English merchant ships the bottom plank is often a mixture of fir, American elm and English elm.

Fir strakes have generally the *after-hoods* of oak, for the better security of the stern-post and rudder, and the forehoods of the same material where the form of the bow requires a great curvature in the plank.

In working the plank of the bottom, including the wales and thick-stuff, the endeavor of the builder should be to bring the plank to the timbers without forcing it upward to the edge of that already worked; or in other words, *edge sets* should be used as little as possible, as the planking that would bear bending one way may be easily broken by an attempt to force it in the opposite direction. Moreover, in working the plank, should the edges be bruised and the bruised portions not removed, early decay of the plank will ensue from the injury which has been received in the grain of the wood. The best method of attaining the desired end, so that the plank can be worked to the bottom of the vessel without being crippled by edge-sets, as well as to meet the difficulties arising from the fact that the girth of the midship body is much greater than that of the fore and after bodies, is *to pen* or bend a broad batten round the timbers of the frame in a longitudinal direction at the breadth in midships of every six or eight strakes of plank, allowing the ends of the batten to take their own position on the timbers of the frame. This arrangement will give spaces fore and aft considerably less than those set off and determined on amidships as the space to be occupied by the six or eight strakes; which decrease of room must be met by making the fore and after shifts or lengths of plank diminish in their width

gradually fore and aft their lengths. Should it be necessary, some of the shifts at the extreme ends may be dispensed with by the use of *steelers.* This diminution in width at the bows and quarters assists in the conversion, as it allows of plank being used there that has sap or unformed wood on its edges, which would be unavailable for the breadth required at the midship portion of the plank of the bottom.*

The plank should be well seasoned before being worked, and to ensure as far as possible the durability of the ship, which would be seriously affected by the materials used in her being green or provided from timber or trees lately cut down, it is advisable, after the plank has been hung to the frame timbers by Blake's screws, that the holes for all fastenings that can be determined should be bored and the frame left open to the draught of air that will be drawn through it, thus allowing the timbers to season well.

The planking in former times was fastened to the timbers of the frame by *treenails,* the practice being in large ships to place in each timber, through the planking, two treenails; this was technically denoted *double fastening.* This mode was found to weaken the timbers, and led to the system of *double and single* fastening in which two treenails are placed through one timber, while each consecutive timber has but one in it.

Treenail fastening has gone out of date at the present time, except in small vessels engaged in the coastwise trade. The wood generally used for making them in this country is *locust.*

Copper bolts, used in connection with short bolt nails of mixed metal, have also been used, but the evils attached to this system of fastening are additional weight (copper being eight times heavier than treenail wood), and the fact that the bolt nail has no hold on the timbers, and is liable to split the plank, and so cause leaks, if not driven with judgment.

It may well be questioned, then, whether in wooden ships good treenail fastening is not quite as good as bolt and dump fastening.

The upper strakes of the planking are sometimes connected to the

* The fore and after ends of the fore and after shifts of each strake of thickstuff and plank are reduced in thickness, that they may be brought round the curved extremes of the ship with less labor, and likewise lessen the depth of the rabbet in the stem or stern-post As a general rule, the thickness of these ends may be taken at three-fourths of the thickstuff and plank amidships in the same strake of planking.

frame of the ship, as shown in fig 49, and the tie thus given to the frame of a vessel is undoubtedly a good one. Thus, in fig. 49, *b* is

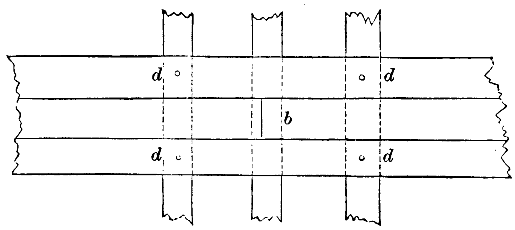


FIG. 49.

the butt of the outside plank, and *dd* dowels placed in the timbers immediately adjacent to the butts, and in the planks above and below them, the butt itself being one-third and two-thirds on the *timber* to ensure wood for the reception of the butt bolt in the two-thirds part; while the one-third wood of the timber forms a good stop for the caulking, the other butt bolt being placed in the adjacent timber of the frame.

Fig. 50 shows the different modes of fastening at the present day.

The outside planking of a wooden ship cannot be permanently fastened until the *inside planking* is "brought to" also, because the fastenings have to pass through both inner and outer *skin.* It is therefore, as before stated, first put on with temporary bolts or screws; and when each strake has been accurately fitted to its place, the treenail holes or bolt holes are bored through the planking and frames; then the inside plank is *brought on,* the holes bored through it and the fastenings driven. The planking in men-of-war is nearly always left for a specified time after the holes have been bored, in order to season the better; a few strakes being left out so as to allow a free circulation of the air.

Preparatory to putting on the *skin* of an *iron ship,* the *sheer-lines* of the sides and *normal*-lines of the bottom are marked on the outside surface of the frames in order to regulate the seams of the *plating.* These lines should be laid off from the builder's draft of the *expansion of the skin,* but the normal-lines may also be easily and accurately constructed on the framing itself by penning a broad, straight-edged and flexible batten to the frames, so as to cross the

midship frame at right angles; when it will of itself assume the true figure of a normal-line.

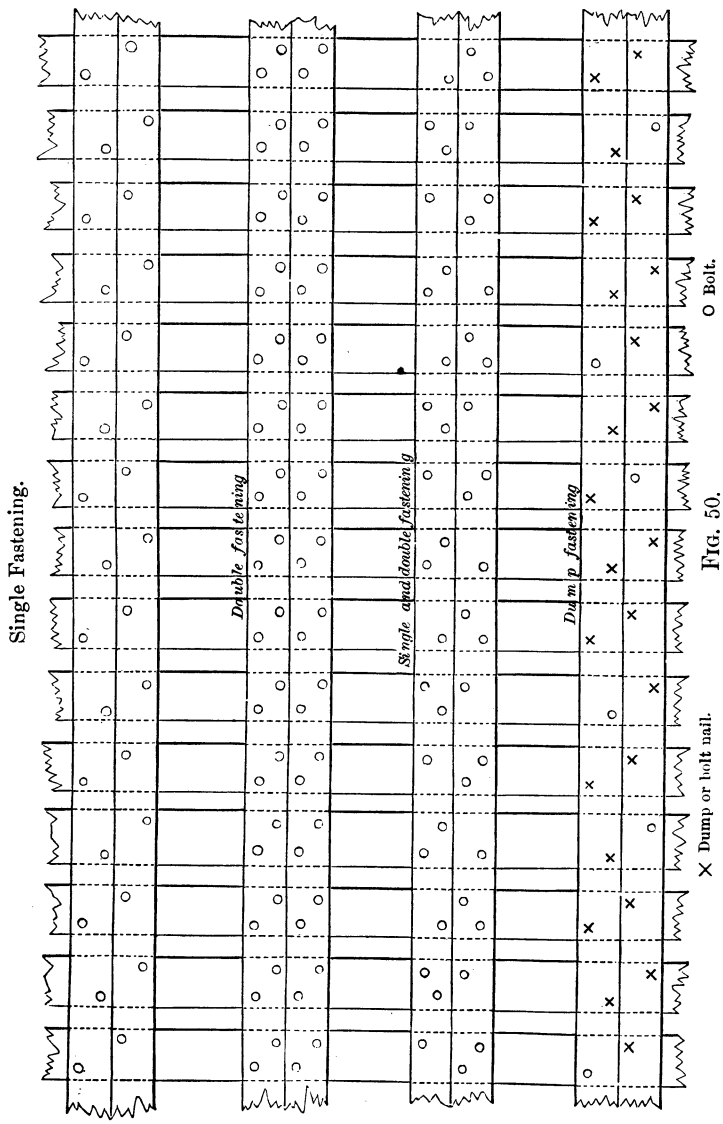


Fig. 50.

The first operation in putting on the skin of an iron ship is to fit

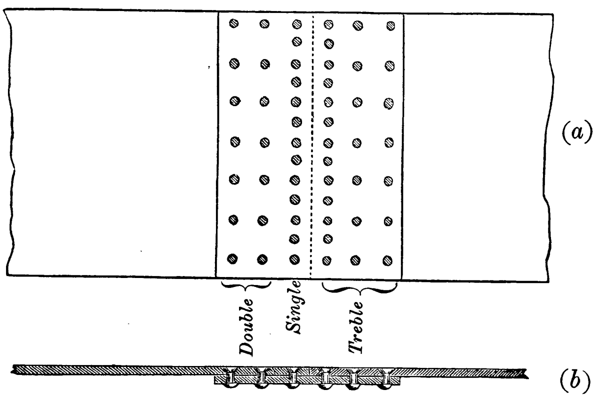


FIG. 51.—*Counter-sunk riveting.*

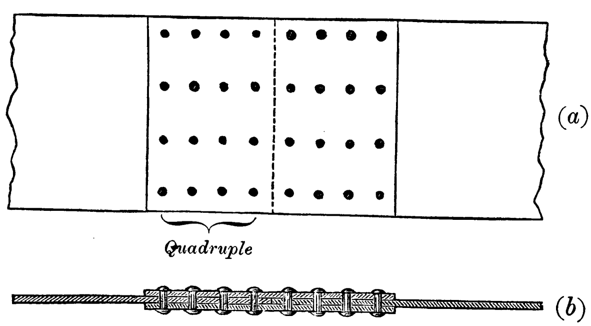


FIG. 52.—*Chain riveting.*

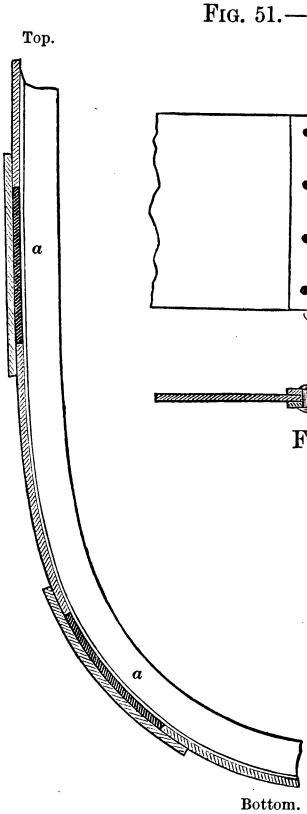


FIG. 53.—*Outside and inside plating.*

the inner strakes of plating (or those which fay to the frames) in their proper places, fastening them in a temporary way with bolts or pins. They are then taken down and the rivet holes are punched or drilled through them; then set up again and riveted to the frames; and the butt straps are also riveted to the inside of the plates at their butt joints. The outer strakes are next fitted on, punched or drilled, and riveted to the frames through the filling pieces (which should be strips of plate completely filling the spaces between the frames and the outer strakes), to the inner strakes at the seams, and to butt straps inside of the butts.

Seams of iron plating are sometimes single riveted, and sometimes double riveted; butts are almost always *double riveted,* and sometimes *treble* or *quadruple riveted.* See figs. 51 and 52.

It may be doubted, however, whether anything more is really necessary than single riveting for the seams, and double riveting for the butts.

The usual lap of plates is from five to six diameters of the rivets at double-riveted joints, and about three diameters at single-riveted joints; the pitch of the rivets, four diameters in seams and butts of plates, and eight diameters in *angle-irons* and other bars.* Fig. 53 shows lap of plates, *aa* being *filling pieces.*

Some of the *riveting* for iron ships (such as fastenings of flanges to the *webs* of beams, etc.) may be performed by the riveting machine, because the work can be carried to the machine; but by far the greater part of it must be done by hand.

The rivets are heated in a small portable furnace, called a *rivet hearth,* which can be carried to any part of the ship. The burning fuel is contained in a shallow, round iron tray, supported by three slender legs. Below the tray is a small circular pair of smith's bellows to blow the fire.

A *set* of *riveters* consists of two *riveters* to clinch the rivets on the outside of the plating; a *holder-up* to put the rivets through the holes from the inside, and hold them steady against the blows of the riveters' hammers; and a boy, or sometimes two, to blow the fire and hand the rivets to the holder-up.

The number of rivets that can be driven by a set of riveters in a

* With a view to the preservation of the plates, it is a good practice, before putting them on, to coat them either with a drying oil or with zinc (galvanizing).

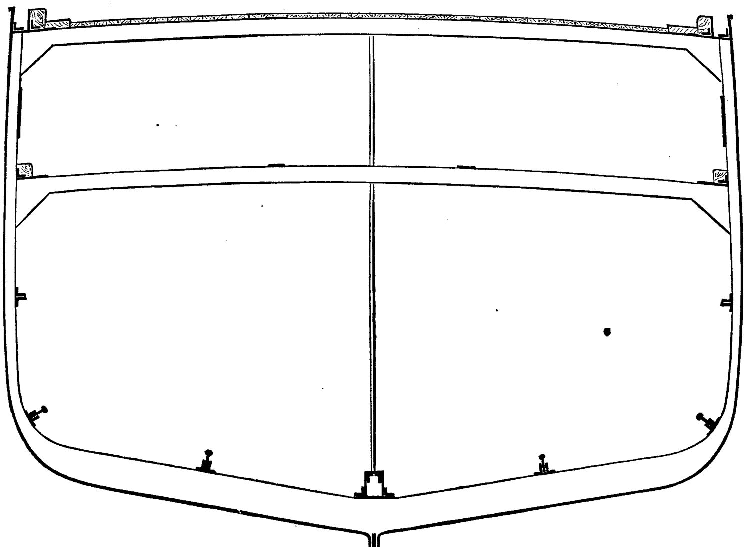


FIG. 54.

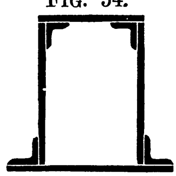


FIG. 55.

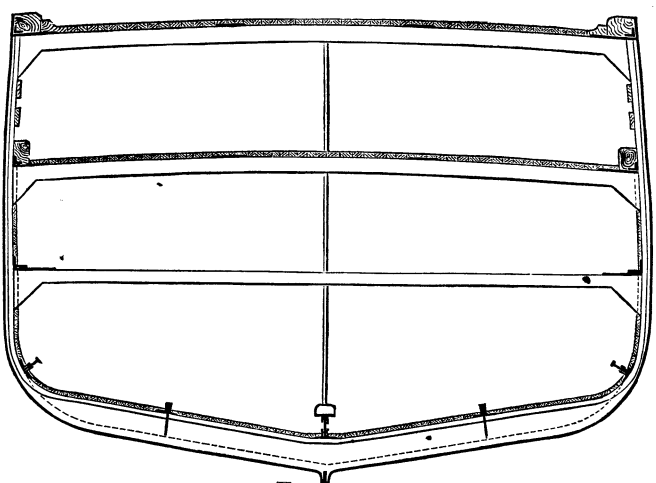


FIG. 56.

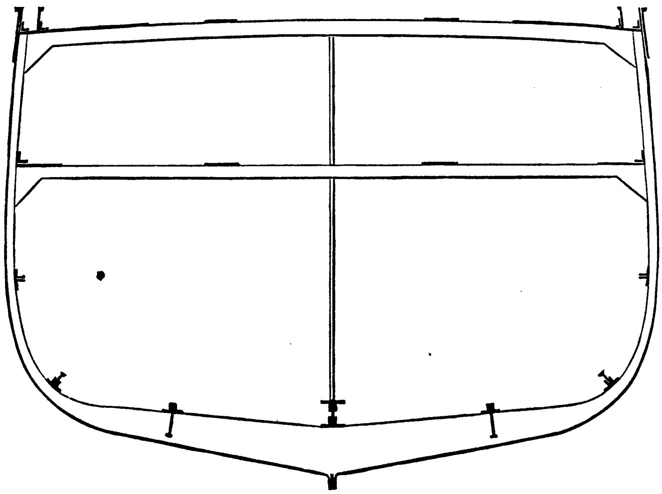


FIG. 57.

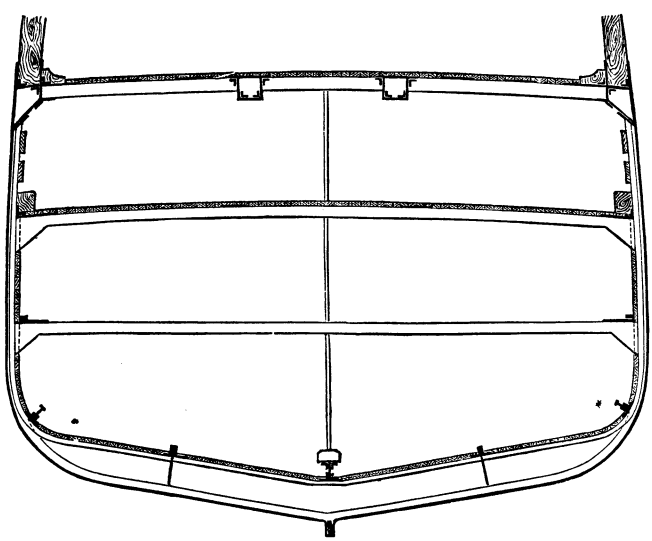


FIG. 58.

day's work of ten hours is about 100, if employed by the day, or 140 if employed by piece-work.

The rivets should be at a bright-red heat during the whole process of riveting up, which should be done very rapidly, that they may not have time to cool.

The clinched end of the rivet when finished should be flush with the outside plating; and should any part project, through being more than sufficient to fill the countersunk hole, it is to be cut off with a chisel.

The pieces used in the hold of an iron ship to give additional strength are *side* and *sister keelsons, hold stringers* and *longitudinal frames.*

When such pieces are fitted between the ribs, instead of being above and inside them, they are called *intercostal* keelsons, stringers, etc.; and in such cases care must be taken to give them sufficient longitudinal connection across the ribs.

In *iron ships* the inner skin is sometimes dispensed with, or else consists of wooden planking, which is bad, and adds little to the strength. In the more recent iron ships, and particularly in the "Great Eastern," another method has been practiced. The bottom, bilges and lower part of the side of the ship have a complete inner skin of iron plating, connected with the outer skin by means of longitudinal and transverse ribs, which divide the space between the two skins into cells. In the "Great Eastern," the two skins are three feet apart. The last method of construction is very favorable to strength and safety, for the inner skin, besides contributing directly to the longitudinal strength of the ship, acts as an inner flange to each of the ribs, longitudinal and transverse; and, should the outer skin be penetrated, the inner skin preserves the vessel from sinking. Figs. 54, 56, 57 and 58 show midship sections in some of the methods of constructing iron ships.

CHAPTER XI.

GETTING IN THE BEAMS AND INSIDE PLANK, FRAMING THE DECKS, ETC., ETC.

In wooden ships the inner skin is sometimes a complete lining to the vessel, at other times only partial. It is almost invariably the custom to work *thick strakes* over the floor heads and first futtock heads. The strakes next the keelson on each side are called the *limber strakes;* see fig. 59, LS, LS. Between them and the keel are two passages for water called *limbers* LL, covered with movable boards LB, LB, called limber-boards, whose upper edges lean against the keelson KS. The point P shows the point from which the *depth of hold* is usually measured.

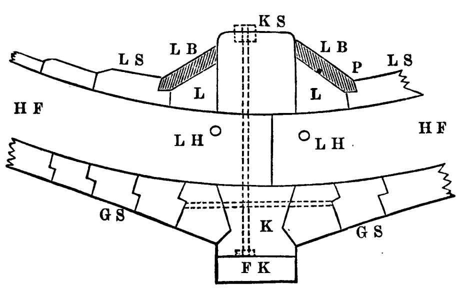


Fig. 59.

The limber strakes and all thick strakes should be worked, if possible, without *edge set;* the number of strakes varying from two to four in the *midships,* and being reduced at the ends by *steelers,* as are the outside planks.

Sometimes it is the custom to work diagonal planks between the thick strakes, but it is considered better to leave the spaces open. The rest of the inside planking of the hold is called the *ceiling* or *footwaling.*

The *clamps* are the strakes immediately below the shelf-pieces which support each tier of beams. In former days, before the introduction of shelf-pieces, the beams rested on the clamps. The plank-

ing between the spirketing (composed of two strakes) and clamps is called *quick work.*

Decks, in ships of different sizes and proportions, vary in number from 1 to 6, the "Great Eastern" having 8. When the decks are numerous, they seldom all extend fore and aft the whole length of the ship; and the ship is said to be *single decked, two decked* or *three decked* according to the number of those decks only which are above the load-water line and complete from stem to stern.

In three-decked ships the lowest deck above water is called the *gun deck* or *lower deck* in ships of war, and *lower deck* in merchant ships; the next above is the *middle deck;* the next, the *main deck;* and the next the *spar or upper deck.*

In two-decked ships, the lowest deck is the *lower* or *gun deck* in ships of war, and *lower* deck in merchantmen; the next above, the *main deck;* the next, the *spar or upper deck.*

In frigates and one-decked merchantmen, the lowest deck is the *main deck* (in men-of-war more properly *gun deck*); the next above it, the *spar or upper deck.*

Corvettes and sloops of war have only one deck with guns on it, called the *upper or spar deck.*

In the old line-of-battle ships, the deck below the *gun deck* was called the *orlop or berth deck;* below that the *cock-pit.*

In merchant ships, the *orlop deck* or *orlop* is sometimes only partially planked, and sometimes consists merely of a tier of beams called *orlop beams,* for giving transverse strength.

In all foreign men-of-war, around the orlop or berth deck runs a *wing passage* to give access to the ship's side, for the purpose of repairing it in action.

If a ship has not a top-gallant forecastle or poop, her spar deck is said to be *flush.*

Side-wheel steamers have a raised platform extending from side to side, amidships, between the paddle boxes, called a *hurricane* or *bridge deck,* and, if narrow in a fore-and-aft or athwartship direction, a *bridge.*

Detached buildings on the spar deck are called *deck houses.*

The clear *height between decks,* from the *flat* or upper surface of the planking of one deck to the under side of the beams of the next deck above, is seldom less than six feet nor more than eight feet.

The *round up*, or convexity of the upper side of a deck, varies from two to eight inches.

The principal part of the framing of a deck consists of *beams* which support and hold together the sides of the vessel.

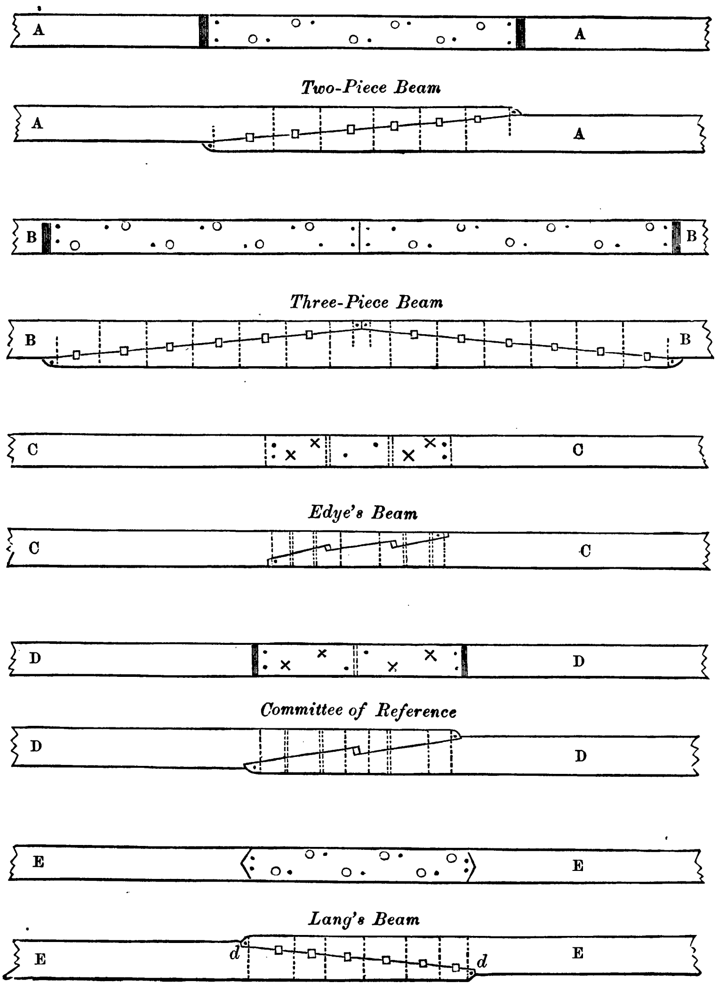


Fig. 60.

In *iron ships* the beams are always of iron (fig. 62); in *wooden ships* they may be either of wood or iron.

If of wood, they are, in large ships, composed of several pieces

scarphed together in various ways, as shown in fig. 60. The scarphs are usually *side scarphs.*

A, in fig. 60, is the beam, as usually put together when the stock of timber will allow of its being made in two pieces, and is technically a "two-piece beam." The dowels employed to connect the scarph are marked thus, °, the bolts, •; and of the two views shown of the beam, the upper is a side or moulded one; and the lower or sided view shows the scarph or overlap of the two pieces, as seen on the upper part of the beam; the scarph being usually one-third the whole length of the beam.

B. In large ships, to obtain the beams, recourse is had to forming the beams of three pieces, of which B is a drawing. The bolts and dowels are the same as described for A, and the scarph is usually one-fourth the length of the beam.

C, the moulded and sided views of a beam on a plan suggested by Mr. Edye, an English shipwright; it is a modification of the key scarph of the joiner of very ancient date. The iron keys, which are shown in the sided way by □, are tapered to form wedges. The lips of the scarph, or the extreme ends of each overlapping part, should be square to the moulded edge of the beam. This beam is secured in its scarph by bolts marked •, and tree-nails marked ×. The scarphs of Mr. Edye's beams run in lengths from 8 feet to 8 feet 6 inches in the beams of a first-rate.

D, a modification of Edye's beam, having only one key to it. This method of scarphing was introduced by the committee of reference instituted by the British Admiralty in 1846.

E, a beam suggested by Mr. Lang, also an English shipwright; it is bolted and coaked in a similar manner to that described for A. The lip let in with a dovetail, *d,* is the characteristic of this plan.

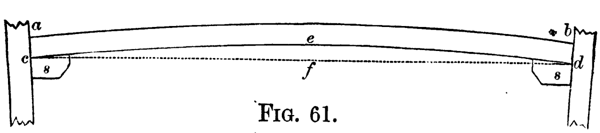


FIG. 61.

The beams should be got in and should rest upon the shelf, *s,* as in fig. 61, where *ef* is the height of the *round up.*

Beams should, as far as possible, be supported amidships by *pillars*

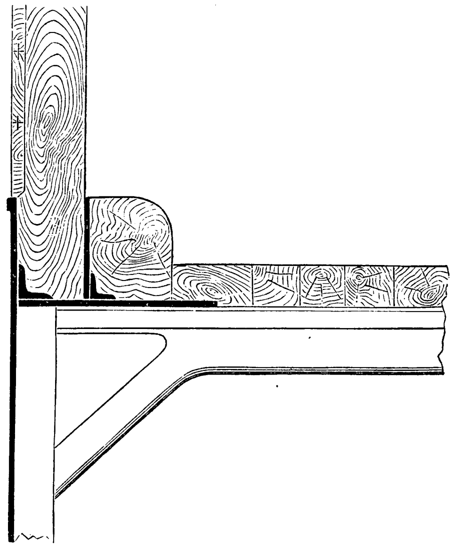


FIG. 62.—*Beam and Deck of an Iron Ship.*

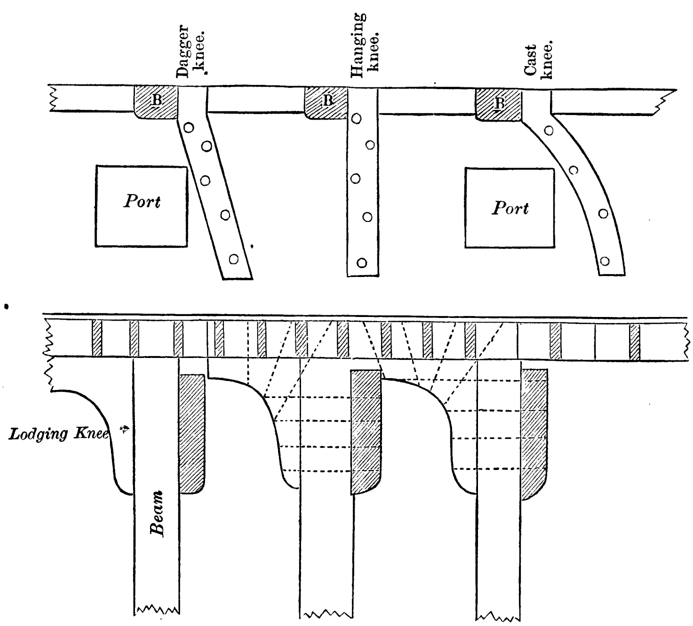


FIG. 63.—*Mode of Working the Dagger, Hanging and Lodging Knees of an Old-fashioned Wooden Ship.*

or *stanchions*, which, when of iron, are usually cylindrical, with projections at the head and heel for fastening them to the beams or keelson.

Sometimes they are, under light decks, movable in the wake of the capstan, and work in a *shoe*.

Half beams are beams running from the ship's side to a *carling*.

Paddle-box beams support the paddle-boxes of a steamer, the outer side being supported by the *spring beams*, which lie parallel to the ship's side and rest upon the paddle beams, which run athwartship and parallel to each other, projecting outside of the ship and forming the foundation on which the *guards* rest.

The rigid connection of the beam ends to the sides is of great importance to both the general and local strength.

In *iron* ships this is effected by iron *knees* or *bracket ends*, which tie the beams to the frame. (See fig. 62.) There are, however, a great variety of modes of doing this.*

In *wooden ships* the beams are united to the side by wooden or iron *knees* of a variety of forms, aided by the mode of fastening the shelf-pieces and *water-ways*, which latter keep the beams *down* on the shelf. The old mode is shown in fig. 63.

The most general arrangement of these fastenings now-a-days is

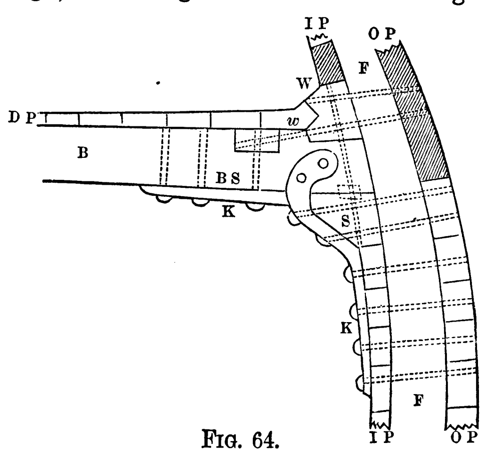


FIG. 64.

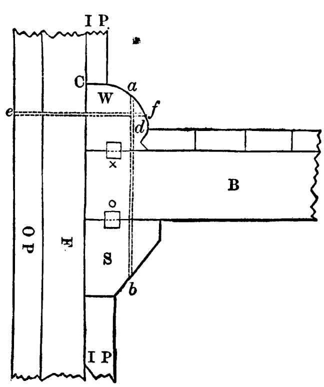
shown in fig. 64, which represents a cross section of part of the side of a wooden ship.

* See "Lloyd's Rules."

F is a frame; OP the outside planking; IP the inside planking; B a deck beam; DP the *flat* of the deck; S the shelf to which the beam end is coaked, the coak being marked by dots □; W the *thick* waterway; *w* the *thin waterway,* being of a gradually diminishing thickness from the thick waterway to the flat of the deck; BS the *binding strake* or *letting-down strake,* half notched to the beams; K a *forked iron knee.* This knee has four arms: one called the *beam arm* is bolted to the under side of the beam; another called the *side arm* to the ship's side, through the frame, and if necessary through a chock of such a shape and size as may be required to fill the space; the two remaining arms form a fork, embracing the sides of the beam and bolted through it. The positions of the bolts are marked by dotted lines.

The butts of the thick waterways are not scarphed or overlapped like those of the shelf. They are placed over a carling between the beams; and on decks having ports the butts of the waterway should be *under* the ports to give shift to the butts of the spirketing and to the ports.

Another very effectual way of uniting the beam-end to the waterway is to dowel the two together and bolt the shelf, beam-end and waterway together, as shown in fig. 65.



× Dowel in waterway and beam.

O Dowel in shelf and beam.

ab, Bolt through waterway, beam and shelf.

ef, In-and-out bolt through waterway, timbers and outside plank.

Fig. 65.

In men-of-war the waterway requires to be *chined* or gouged out, as in fig. 66, in order that the forward gun trucks may take closer to the thick waterway, and thus allow of more *lateral train.*

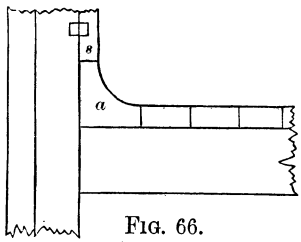


FIG. 66.

The *spirketing* (*s*) should be doweled to the timbers of the frame to keep the beams and waterways perfectly rigid in a seaway.

In men-of-war the *clamps* work down to form the *upper portsill*, while the *spirketing* works up to form the *lower portsill;* both clamps and spirketing being bolted edgewise, as in fig. 67.

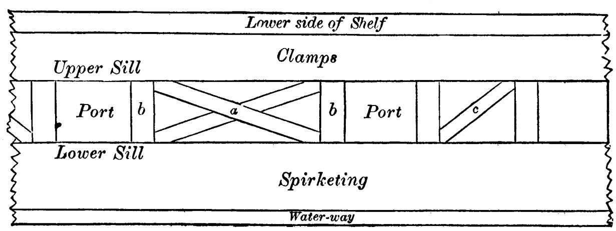


FIG. 67.

The space between the clamps and spirketing is shut in with thin plank called shortstuff, and, when worked in, is called the *quick work*. This is sometimes worked diagonally or brace-fashion.

In fig. 67, *b* is the abutment piece, and *a* the *truss* or *brace;* the truss *c* being reversed in the spaces between the after ports. This method has fallen into disuse on account of the expense of conversion.

The following description of the midship section (fig. 68) will be found useful in showing the relative positions of the strakes of planking, both inside and out:

a, Half section of the keel.
b, False keel.

Outside planking:
ee, Garboard strakes of outside planking.
ff, Plank of the bottom.
gg, Diminishing plank.
h, Wales.
z, Black strakes.
xy, Sheer strakes.

Sections showing the Timbers of the Frame, and the Positions of the Outside and Inside Planking of a Ship.

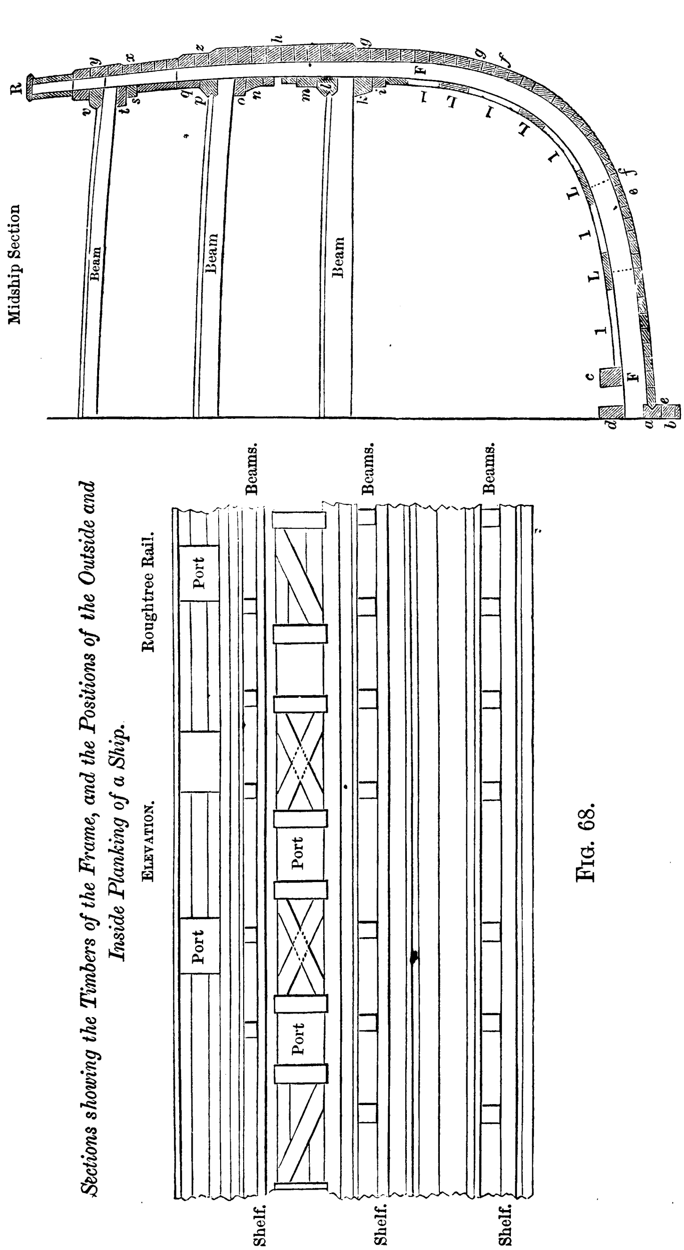


Fig. 68.

R, Roughtree rail.
v, Water-way to spar deck.
t, Shelf to spar deck.
s, Clamps " "
q, Main-deck spirketing.
p, Main-deck water-way.
o, Main-deck shelf.
n, Main-deck clamps.
m, Berth-deck spirketing.
l, Berth-deck water-way.
k, Berth-deck shelf.
i, Berth-deck clamps.
LLLL, Thick strakes worked over the heads of the 3d, 2d and 1st futtocks and floors.
1111, Spaces between the thick strakes.
c, Side keelsons.
d, Main keelson.
F, Head of the fillings of wood, placed in between the timbers as described in the text, under the head of fillings between frame timbers.

The elevation in fig. 68 shows the position of the ports and the trussing between them.

In *iron ships* the water-ways are usually made of iron plates lying flat on the beams, though they sometimes have a rising flange or ledge at the inner edge of the depth of the planking, so as to form an open channel for water; and are sometimes covered by wooden water-ways.

Fig. 57 (page 362) will show the first method referred to; while figs. 54, 56, 58 and 62 will sufficiently describe the more general methods of arranging the water-ways in iron vessels.

Figs. 69, 70, 71, 72, 73, 74 and 75 are representations of knees for securing the beams. They are made of wrought iron, and are considered better than wood, because they occupy less space with greater strength.

Various Styles of Iron-knees. Scale ¼ inch to 1 foot.

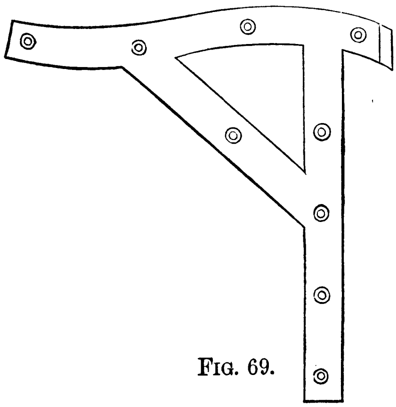


FIG. 69.

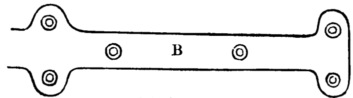
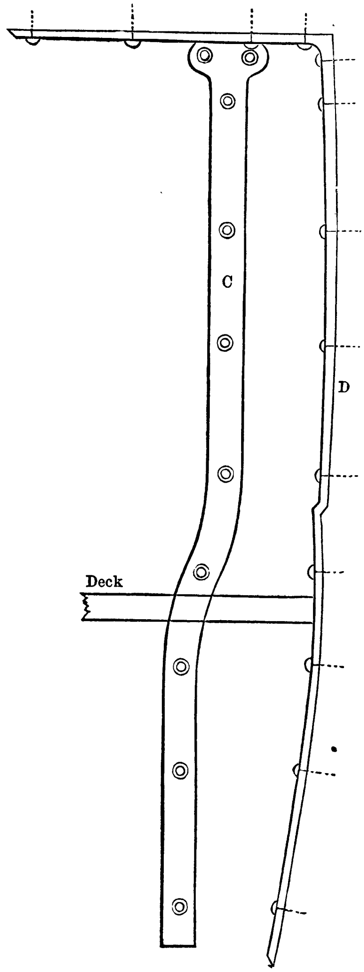


FIG. 70.



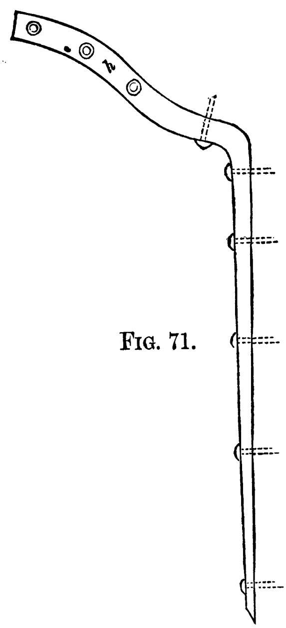


FIG. 71.

Fig. 69.—Robert's plate knee, with waved arm to the beam arm.

Fig. 70.—B, front view of Lang's beam-arm knee; C, front view of Lang's knee (for lower deck beams in heavy ships), which runs down below the orlop deck; D, side view of same knee.

Fig. 71.—Section of a *horn* knee with three bolts in the horn *h* which clasps the beam.

F, fig. 72, section of an iron clutch-knee used in foreign men-of-war. This knee is worked to the internal planking and beam arm.

G, fig. 72, front view of the above knee; the upper bolts are, in

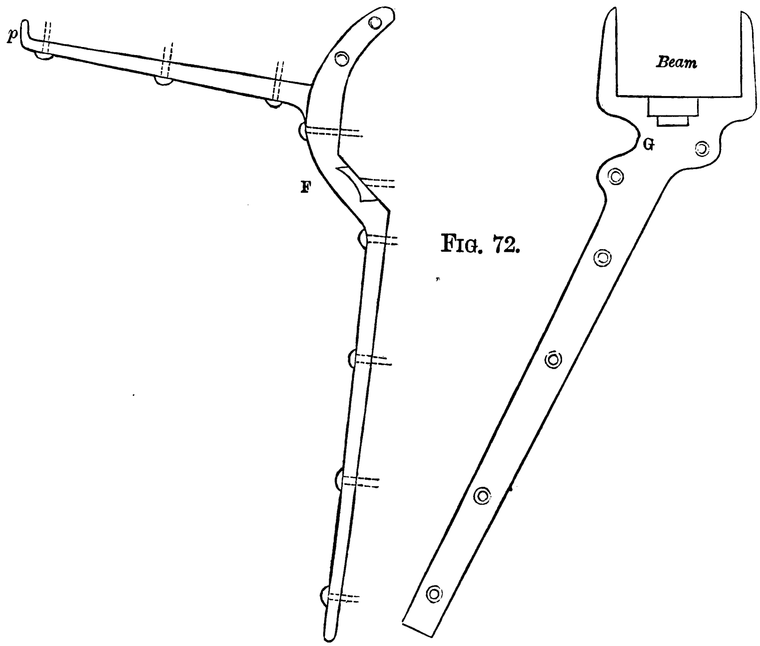


Fig. 72.

large ships, $1\frac{1}{4}$ inches in diameter; the lower ones, $\frac{3}{4}$ of an inch. The point p is turned up into the beam before the iron knee F is bolted.

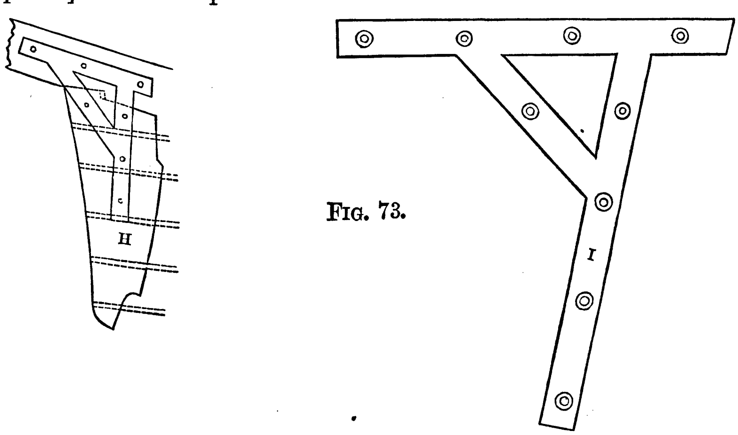


Fig. 73.

Fig. 73 is a plate knee, H showing side section of the beam, and I being

the knee. The objection to this knee is that the bolts in the beam arm, being all in one range of the fibres of the wood, have a tendency to split the beam end.

Fig. 74 is an iron knee used in securing the beam ends of the poop deck. It is usually called a *dog plate;* the upper part of the

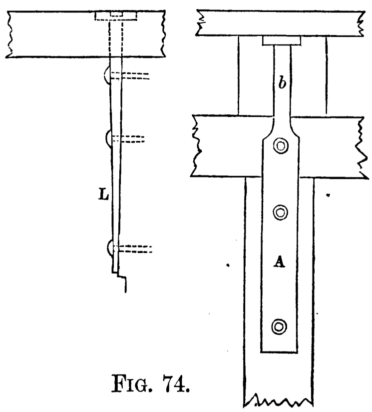


FIG. 74.

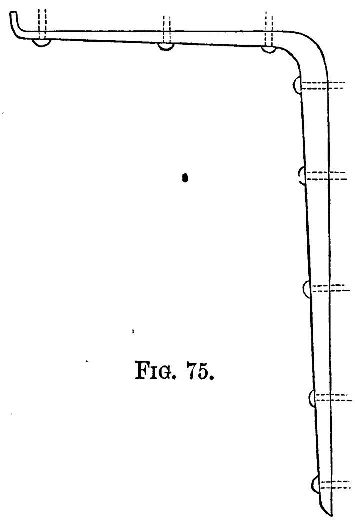


FIG. 75.

knee is formed as a round bolt long enough to pass through the beam; the bolt *b* being clinched above. The bolts in A pass through the shelf and ship's side. L, a side section of A*b*.

Fig. 75—Hanging knee of iron.

CHAPTER XII.

BREAST-HOOKS AND CRUTCHES—DECK-HOOKS AND TRANSOMS—HATCHES AND SCUTTLES—BITTS AND STOPPERS—HAMMOCK NETTINGS—CHANNELS—FASTENINGS, ETC.

To unite the two sides of the ship together forward and aft—where the lower timbers do not cross the keel—inside timbers or plates are worked.

Forward, these are termed *breast-hooks*; aft, they are called *crutches.*

The arms of the breast-hooks and crutches extend equally on each side of the middle line, being widest at their *throat* and tapering toward each end of the arm. (See figs. 77 and 78).

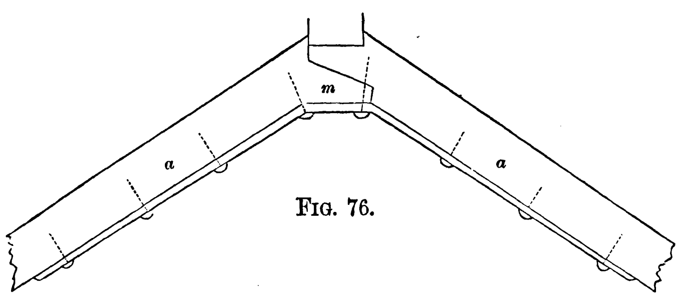


Fig. 76.

Fig. 76 is a deck-hook; *aa* being ekings of wood the same depth as the moulding of the beams; they are scarphed together at the middle (*m*), and an iron hook is then worked over them of the breadth of 5 or 6 inches. The bolts in the *throat* of the deck-hook are, in a large ship, $1\frac{1}{4}$-inch bolts, and those at the ends are $\frac{3}{4}$ or $\frac{7}{8}$ of an inch in diameter.

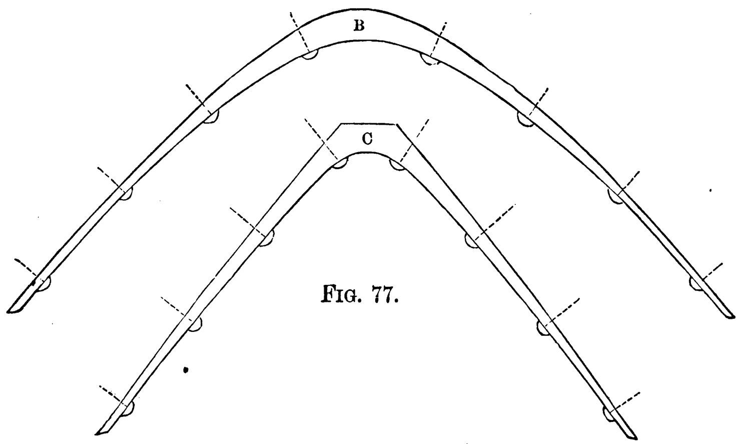


FIG. 77.

B and C (fig. 77) are iron *breast-hooks.*

Fig. 78, iron crutches used to connect the two sides of the ship at the after extreme; the centres *b* and *c* being placed on the upper side of the after *deadwood*, the *arms* lying across the *heels* of the timbers, so that the bolts shown in the figure are each in separate timbers.

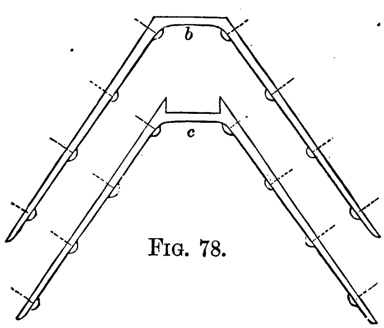


FIG. 78.

The breast-hooks are equally spaced between the *deck-hooks*, which serve to unite the forward and after parts of the decks to the sides and beams.

They are also placed square to the stem and the form of the bow, by which they cross several of the cant timbers and tie them to the stem.

The deck-hooks must have their upper surfaces fair with the round up of the beam and sheer of the decks, and therefore their position is fixed by the height of the several decks.

The difficulty which attends the conversion of timber into breast-hooks, deck-hooks and crutches has led to their being, in some instances, made wholly of iron; in others, of a combination of wood and iron; and again, of an assemblage of wooden pieces. When wholly of iron, they are strapped over the apron, as shown in fig. 79 (*c*).

When composed of wood and iron, two arms of wood, called *ekings,* are worked, the upper surface being flush with the upper side of the apron, while on the upper side of these an iron breast-hook or plate of iron is placed and bolted through the frame-timbers and planks. When formed of wood, two ekings are worked, as pointed out in the combination of wood and iron (D), and then a wood hook over them, the whole being bolted to the ship's bottom.

The size of the bolts used in these ties for connecting the sides of the ship at the fore and after extremes vary, even in the same hook or crutch, the bolts in the *throat* of the hook being larger than those in the *arms.* The bolts in wooden breast-hooks should be placed across (as 1 1, 2 2 in D fig. 79) in order to bring the fastening square to the outside plank.

The bolts should be spaced on the upper and lower edges of the depths of these hooks, such depths being in the deck-hooks usually the moulding of the beams of the respective decks.

The foundations for the decks aft are called deck transoms; they are worked in a similar manner to the deck-hooks in the forward part of the ship.

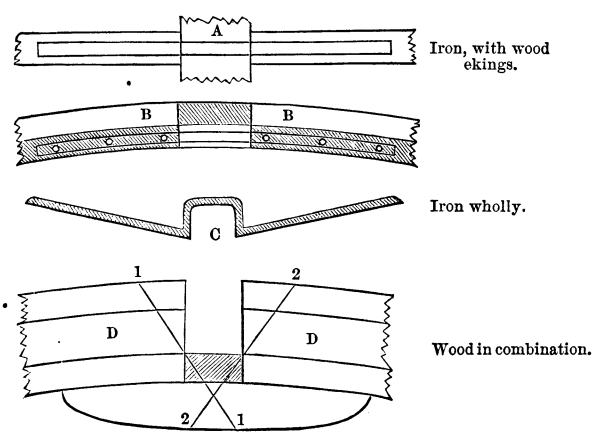


FIG. 79.

In square-sterned ships the *wing transom* forms the base of the stern.

The beams having been gotten into place and pillared, the knees

worked, and the water-ways and spirketing placed over the beams, the next step in building is to *frame the decks.*

First in order are the *mast-holes* or *mast-rooms.* These are larger than their respective masts, at their several heights, by double the thickness of the *mast-wedges,* and the wedges vary in thickness from 3 to 6 inches, according to the size of the vessel.

The framing of a mast-hole, where wedges are used, is composed of *fore-and-aft partners, cross-partners* and *corner-chocks.* There should be a coaming around each mast-hole. French men-of-war have sometimes the cross-partners of the foremast movable on the several decks, in order to admit of an alteration in the rake and step of the foremast.

Next come the openings in the deck for giving access to the decks below, called *ladder-ways* and *hatchways.*

Hatchways are formed of four pieces, two placed fore and aft, called *coamings,* and two placed athwartships, called *head-ledges* (fig. 80). The head-ledges rest on the beams, and the coamings on pieces called *carlings* placed under them and reaching from beam to beam.

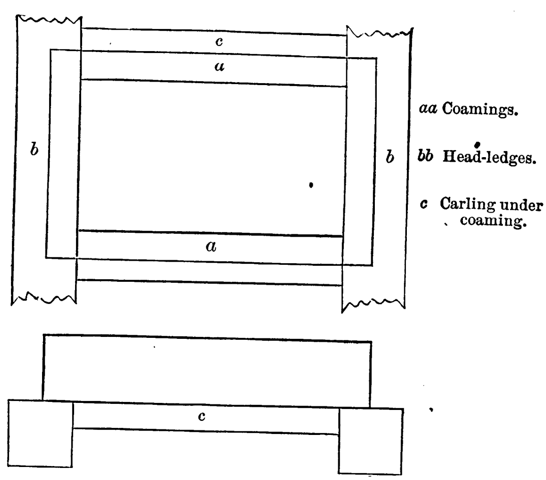


Fig. 80.

The carling *c* is worked 2 inches wider than the *coamings,* to form a support to the strake of *deck-flat* that comes on it. The head-ledges and coamings are doweled and bolted to the beams and carlings. The coamings have a rabbet taken out of them to receive the gratings for covering the hatches.

The height of the coamings varies in different ships; those ships which take much water aboard in a sea-way should have the highest coamings.

The coverings over the ladder-ways are called *companions*; sometimes *booby-hatches.*

Iron ships have iron carlings.

The *flat of the deck* usually consists of plank lying fore and aft; sometimes the planking of the deck is laid diagonally, in order to give transverse stiffness; but it is better to lay it fore and aft for the sake of longitudinal strength, and to obtain transverse stiffness by means of flat *diagonal braces* of iron laid above the beams and below the planking.

In iron ships, great additional longitudinal strength is gained by plating the upper deck with iron, over which planking is laid. (Fig. 58.) The same object is gained in wooden and iron ships by means of *deck-stringers.* In wooden ships, next to the thick water-way at the side, a plank 1 inch greater in thickness than the deck is worked; one edge being placed in a rabbet formed in the main water-way for its reception; this is called the *thin water-way.* The inner edge is reduced to the thickness of the deck plank, and the use of the thin waterway is to receive the ends of the decks forward and aft, as shown by fig. 81. In large ships the thin water-way should be bolted with

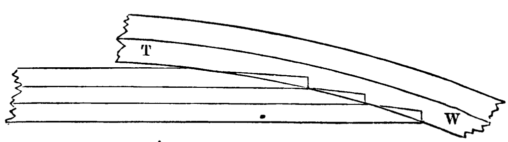


FIG. 81.

short bolts into the beam, to resist the caulking of the seam of the thick water-way.

There are in double-decked vessels two pair of riding bitts for the bower and sheet chain cables. Fig. 82 shows those generally in use at the present time, the bitt used in the United States Navy being a slight modification of fig. 82.

A, in fig. 82 (a), is a worm or thread cast in the iron hood (h), which forms the separation between the turns of the chain cable, two of which can be taken round the bitt head when thus fitted.

Fig. 82 (b) is a plan of the bitt head, with the iron hood (h) round it.

B and C, mortises or holes cut through the iron hood (*h*) to receive the cable supports, and thus keep the turns of the cable sepa-

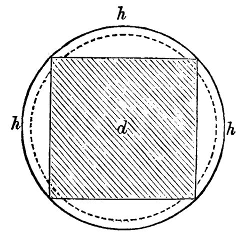


FIG. 82 (*b*).

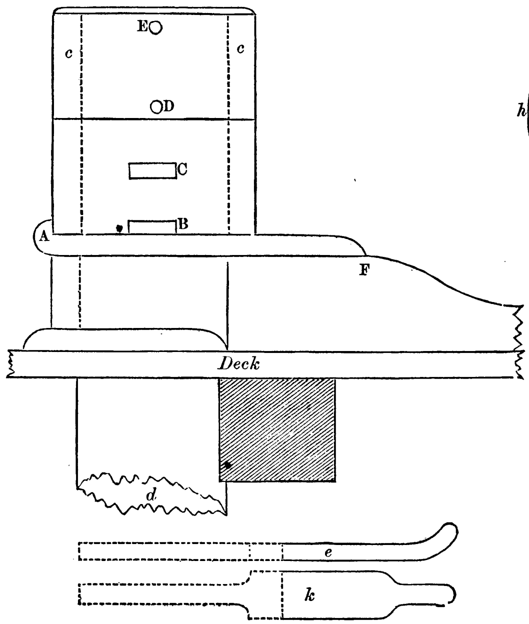


FIG. 82 (*a*).

rate. The cable supports inserted in these mortises are shown by sections; that of plan being marked *k*, and elevation *e*.

D and E, holes through the upper casting (*c*), to receive bitt-pins which prevent the upper turns of the cable from flying off over the bitt head when the cable is veered rapidly.

F, standard or wood knee to the riding bitt, to which the flange of the lower hood is secured—the standard (F) being principally designed to support the riding bitt and resist the strain brought on it. The standard should be, in height from the deck, about twice the circumference of the cable.

Cable supports are usually called *cavils.*

These bitts should run down through two decks, but the stanchion (*d*) is not secured by a standard on the lower one.

Figs. 83 and 84 give another view of a pair of riding bitts used in heavy ships.

Fig. 83 is a *side elevation*, and fig. 84 a *plan*. DB, DB, DB, are lower or main deck beams; OB, an orlop or berth deck beam; BB,

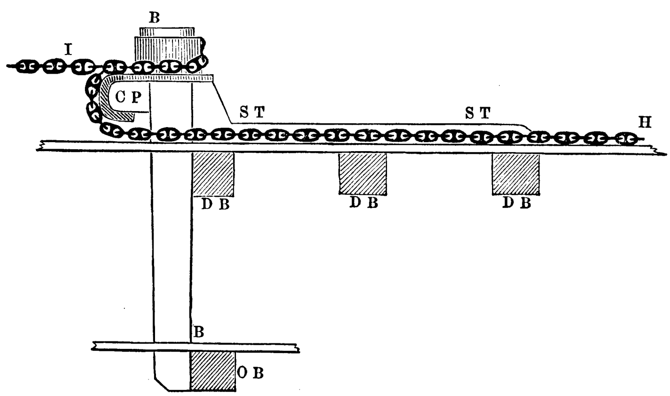


FIG. 83.

are the *bitts*; CP, a *cross-piece*; ST, ST, are two *standards* or horizontal knees, bolted to three beams in order to resist the forward pull

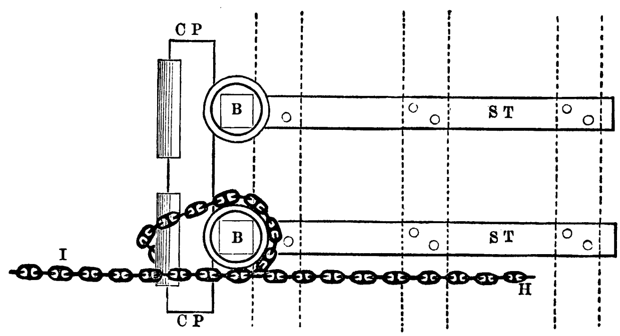


FIG. 84.

of the cable; HI, is the chain cable; H, being toward the *hawse-hole*, and I toward the chain-locker.

These bitts are generally of wood, with a casing of iron.

ST is sometimes called a *Sampson knee*.

Single-decked vessels have but one pair of riding bitts.

In the merchant service the *windlass* answers for bitts as well as *capstan*.

The *hawse-holes* for the cables are four in number (except in small

vessels, which have only two), and are usually placed in range of the main deck and between the *cheeks* of the head. They pass through two thick pieces of wood called the *bolsters of the hawse*, each bolted outside the plating or planking of the bows. Each hawse-hole is lined with a cast-iron *hawse-pipe*, the usual dimensions of which are nearly as follows:

Inside diameter, from 9 to 10 times the diameter of the cable iron; thickness, three-fourths of the diameter of the cable iron.

The *hawse-holes* are stopped when required with *bucklers*, which work on a hinge; a score being taken out to admit the link of the cable.

Scuppers are holes lined with lead or mixed metal, and sometimes galvanized iron, for discharging water from the deck to the sea. Each of these pipes is sometimes made in two lengths, connected respectively with the outer and the inner skin.

A short way abaft the hawse-holes on the working deck is a low upright partition, composed of plank (shod with a casing of iron) lying athwartships. This is called the *manger-board*, and is to prevent the water which may come in at the hawse-holes from flooding the deck.

The space included inside the manger-boards is called the *manger*, and a pair of scupper-holes for discharging the water the *manger-scuppers.*

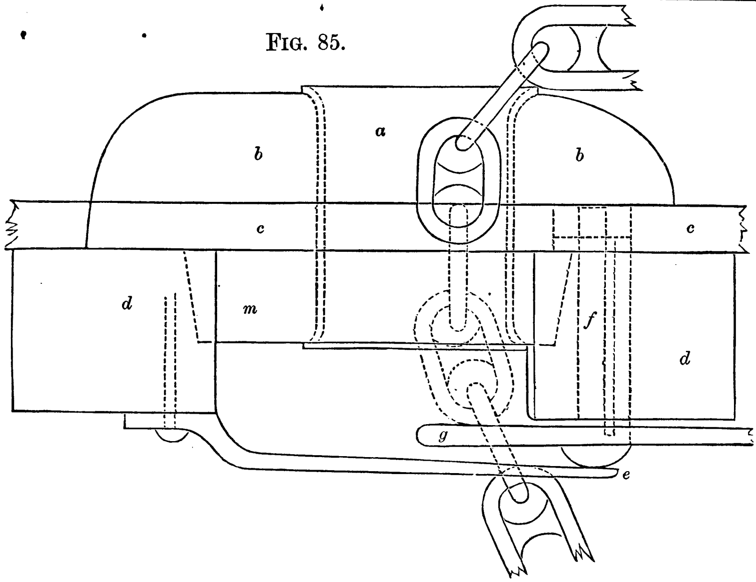
The ends of the manger-boards fit into rabbets in upright pieces called *manger-stanchions*, of which there are either two or four, according as the boards are in two or three lengths.

Mangers are now little used in merchant vessels, since they are rendered unnecessary by the hawse-pipes being made to slope upward from the hawse-holes, and so to conduct the cables to the deck next above the hawse-holes instead of that next below.

For the purpose of regulating and checking the motion of the cable as it runs toward the hawse-holes, *controllers* are used in connection with the bitts and *berth-deck compressors.*

A *controller* is a cast-iron block, having a hollow in its upper side of the shape of a link of the chain cable. They are bolted to the deck forward of the bitts, and also (in large ships) forward of the *chain locker-pipe.* The cable while lying on the controller tends of itself to drop into the hollow *slot*, and while there it is held by one

FIG. 85.



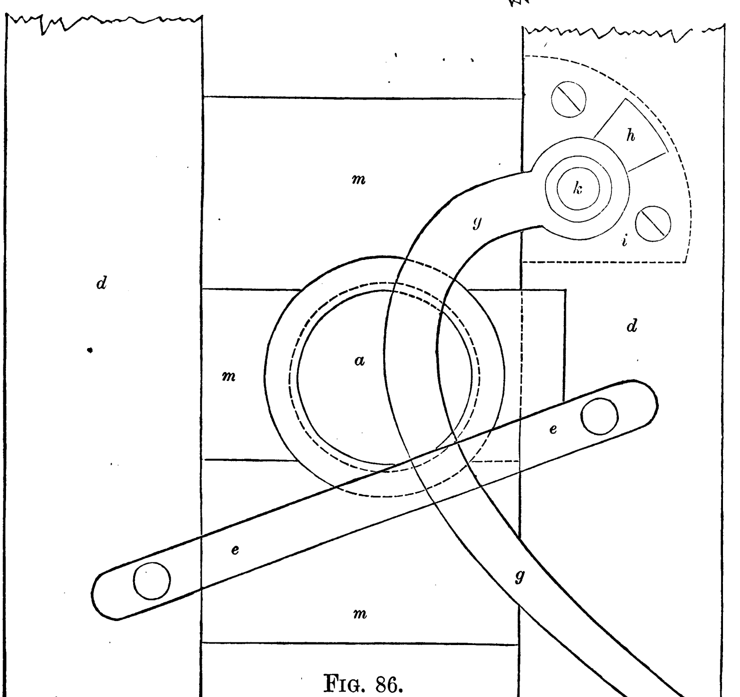


FIG. 86.

Scale 1 inch to the foot.

of its links which lies flat in the hollow; but at the bottom of the hollow is a *jog* or short lever arm which can be raised by a longer lever, and so lift the cable out of the slot when it runs out until the lever is let go and the *jog* dropped.

The compressor in general use is shown in figs. 85 and 86.

Description of the Elevation and Plan of a Compressor (figs. 85 *and* 86) *for checking the Chain Cable when running out round the Riding Bitts.*

Fig. 85.—*Elevation.*

a, Section of iron pipe for the cable to run through.

b, A chock let down through the deck (*c*) to the beams, *d, d.*

c, Deck,

d, d, Beams.

g, Compressor or bent lever pivoting on the bolt *f,* which, by the use of a tackle, is made to nip the chain against the pipe and beam. The chain cable has been found to force down the compressor and the bolt (*f*), which has caused the introduction of the strap (*e*) bolted to the beams (*d, d*).

m, Carlings let down between the beams (*d,d*) to form a bed for the iron pipes, *a.*

Fig. 86.—*Plan of the Compressor, and supposed to represent the underside of the Deck and Beams.*

a, Pipe for the chain cable, which in men-of-war is two-thirds of the diameter of the *hawse-hole* in the clear.

dd, Underside of the beams.

g, A section of the compressor.

k, Head of the bolt (*f* of elevation) on which the compressor revolves.

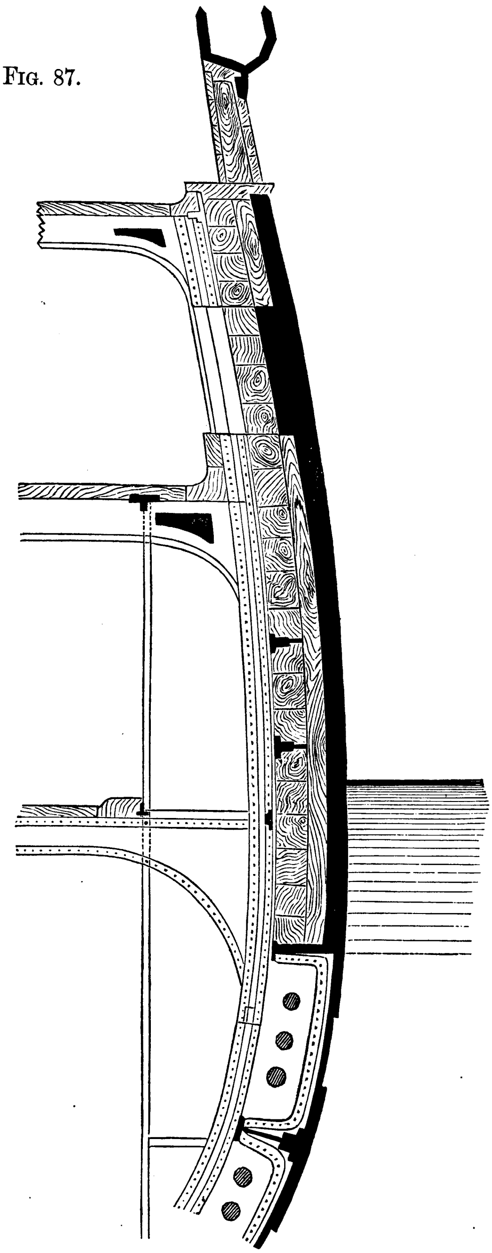
h, A fan or counterbalancing arm worked in the compressor to assist the staple *e* in keeping the compressor in its place.

i, An iron plate screwed on to the underside of the beam, to form a hard surface for the fan (*h*) to work upon.

e, Strap to support the compressor (*g*).

This compressor was invented by Captain Chasman, of the British Navy, the addition of the fan (*h*) and strap (*e*) being suggested by practice.

FIG. 87.



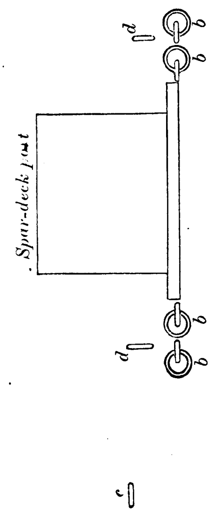


FIG. 88.

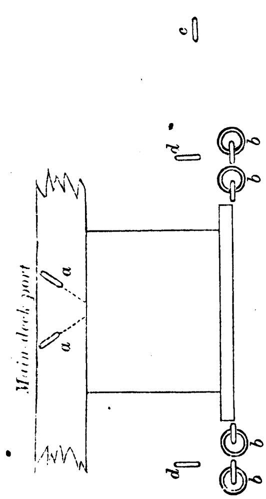


FIG. 89.

The decks and the beams, stanchions and bulkheads of a man-of-war must be of a strength sufficient to bear the weight of the battery.

In ships pierced with *port-holes* for guns, the longitudinal strength thus taken away must be supplied by adding sufficiently to the sectional area of the skin and framing above and below the ports. In iron ships of war (of the broadside type) the skin above and below the tiers of the port-holes is doubled, and longitudinal stringers are fixed outside. Port-holes were formerly made about 4 feet square; at present, though the height is not much diminished, the breadth is in iron-cased ships reduced to 2 feet, and in turret ships to little more than the width of the gun.

The distance apart from centre to centre ranges from 10 to 18 feet, according to the battery carried. The lowest port-sill should be at such a height as not, in a two-decked vessel, to be immersed by a roll of from 10° to 12°, and in a single-decked vessel by a roll of from 15° to 20°.

In ships of war not armored, each port-hole is closed by a *port-lid* opening upward, or by a pair of port-lids opening, one upward and the other downward, and called *half ports.*

Figs. 88 and 89 show the elevation of two ports—one a *spar-deck port,* the other a *main-deck port.*

aa, fig. 89, eye-bolts in the shelf of the main deck, called muzzle-lashing

bolts. The muzzle of the gun in bad weather is placed against the shelf between them, and a strong lashing passed round it and through the eye-bolts (*aa*). Bolts $\frac{7}{8}$ inch in diameter.

dd, Eye bolts for the side tackles, $\frac{7}{8}$ inch in diameter.

c, *Eye bolts* placed between the ports for extreme training of the muzzle of the gun as far forward or aft as the side will admit, called "*fighting bolts.*"

bb, *Breeching* and *preventer-breeching bolts;* the first from the side of the port receives the breeching used to restrain the recoil of the gun; the other, or preventer-bolt, being intended as a resource in the event of the first drawing.

The ports in the United States Navy admit of 11° elevation and 9° depression. The remainder of the fittings about the decks may be comprised as follow:

Scuttles or *light ports* are small openings for light and air, and in iron ships are round. In wooden ships they are round in men-of-war, and square in merchantmen.

They are closed by panes of heavy glass (sometimes ground) set in strong metal frames, and, if necessary in bad weather, by *dead-lights* or water-tight *air-ports.*

The term *scuttle* is also applied to small hatches in the decks, and their covers are called *cap scuttles.*

The *cabin ports* or *windows* are less used in iron than in wooden ships. They are of various shapes, more or less distorted, so as to suit the round-up of the decks and the *rake* of the counter-timbers. They are arranged to close in bad weather by water-tight shutters called *dead-lights.*

In wooden ships of war they sometimes open upon overhanging balconies, called *stern galleries* and *quarter galleries.*

Bulkheads or partitions are sometimes used to give transverse strength to the ship and divide her into *water-tight compartments.*

Bulkheads of lighter construction, and capable of being removed when required, are used to enclose state-rooms, cabins, etc., and to separate apartments in the ship.

Longitudinal or *fore-and-aft bulkheads* are sometimes used to add to the longitudinal strength of the ship. They act like the web of a girder, to resist longitudinal racking and bending.

For the same purpose, *longitudinal girders* or *hog frames* are

sometimes used in long, shallow vessels like the North river steamboats.

These consist of an upper and lower *stringer*, connected together by a skeleton framework of upright and diagonal braces. The upper stringer is usually arched, and the lower stringer may form a keelson.

Sometimes the duties of the upper stringer are done by iron-rod or wire *stay-ropes*, descending obliquely from the heads of upright masts or stanchions to the ends of the vessel. This latter is usually termed a *hog frame*.

Bulwarks are those parts of the ship which rise above the spar deck.

The waist, quarter deck and forecastle, or the flush deck, of all ships of war and of some merchant ships have close bulwarks. Their vertical framing in wooden ships consists of the top timbers of the frame; in iron ships it may consist of the tops of the frames or of strong wooden *bulwark stanchions* secured to the tops of the frames and to the inside of the sheer strake. The outside of the bulwarks may be either plated or planked, and the inside also, if required. Along the top runs a piece called the *gunwale* at the waist of a ship, and the *plank sheer* at the quarter deck and forecastle of a ship with a waist, and throughout the whole length of a flush-decked ship. The upright or curved pieces of timber that connect the gunwale with the plank sheer are called *drift pieces*. In some merchant ships the gunwale is continued all round, a little above the level of the quarter deck and forecastle (or spar deck, as the case may be); and those decks have, instead of bulwarks, an open railing, with or without a netting. The poop, top-gallant forecastle and bridge have almost always an open railing only. The bulwarks may be made to contribute to the general strength of the ship.

A railing or balustrade standing athwartships across a deck—say, for, example, at the *break* of the poop or top-gallant forecastle—is called a *breast-work*, and the beam under it a breast-beam.

Above the gunwales of ships of war are fixed the *hammock nettings*, consisting of a row of forked, upright iron or wooden stanchions, supporting a *netting* in which are stowed the hammocks. (See figs. 90 and 91.)

Hammock Nettings.

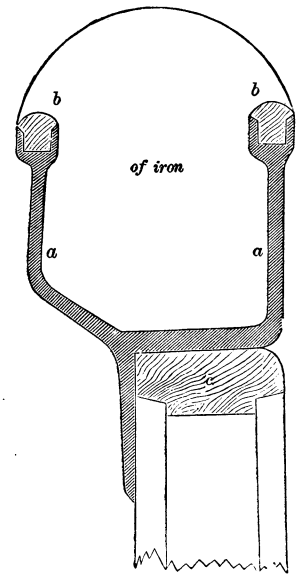


FIG. 90.

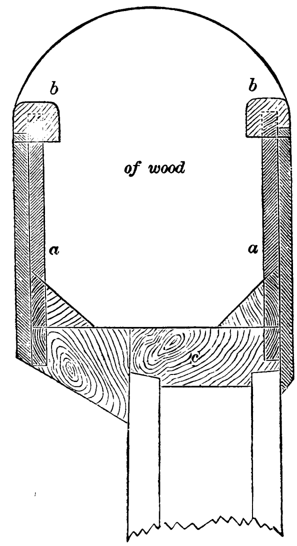


FIG. 91.

(*a*), fig. 90, hammock stanchions of iron, with horns to receive the rails. (*b*), rails, 3 inches by $2\frac{1}{2}$ inches, to form, with berthing or board of $\frac{7}{8}$ths inch thickness, the *nettings* fore and aft for the hammocks. (*c*), roughtree rail.

Fig. 91, the same, made wholly of wood.

Channels are flat ledges of wood or iron projecting outboard from the ship's sides, for spreading the lower shrouds. The *extent of projection* is made sufficient to carry the shrouds some five inches clear of the hammock-rails, either outboard or inboard. Generally the shrouds pass outboard of the rail, but in some cases they are made to pass inboard, and are in such cases *housed* in the *hammock netting.*

Ships are often made without channels, the chain-plates being secured to the gunwale or the sheer strake.

The foremost end of the channels is usually so placed as to be nearly abreast of the fore side of the lower mast to which they belong. The *length* of the channels, in a fore-and-aft direction, is, on an average, about one-half of the length of the lower mast from spar deck to cap.

One-half the length from *hounds* to spar deck is the part usually

occupied by the spread of the rigging. The thickness of the channels is about once and a half that of the skin of the ship's side where they are fastened on, supposing the material to be the same. Wooden channels are made from one-third to one-fourth thinner than this at the outer edge, which is sometimes bound with an iron bar or plate of the same depth called the *guard-plate.* Channels are bolted to the ship's side edgewise with 'thwartship bolts at intervals of about three feet, and are supported from below by wrought-iron knees or brackets at about the same interval apart. The planks of which wooden channels are built are coaked together at their edges with coaks at about the same interval also.

The *chains* pass over the edge of the channels through a notch, and are fastened to the side by the *chain-plates,* in the *toe-link* of

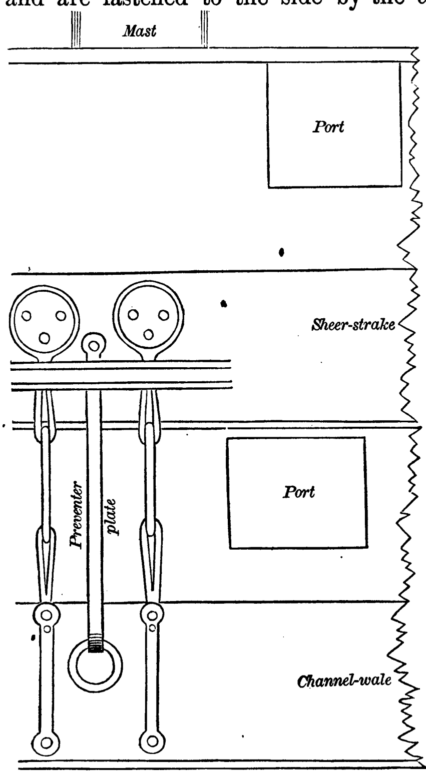


FIG. 92 (A).

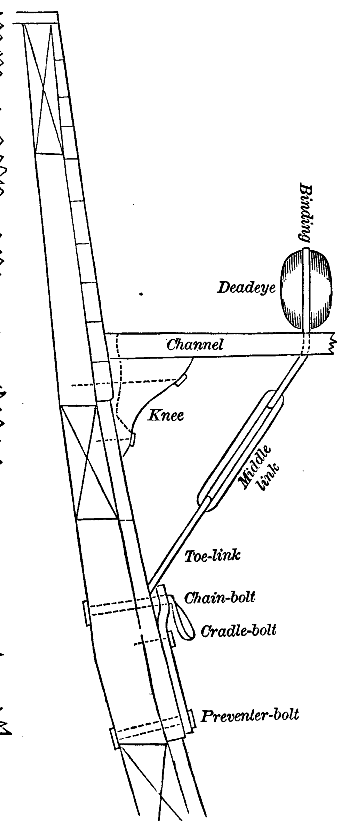


FIG. 92 (B).

which are the *cradle-bolts*. To the upper part of the chains the *bindings* of the *deadeyes* are secured. (See fig. 92, A and B.)

All bolts, that are used in fastening any portion of the timbers or frame, should pass through *washers* or *rings* at their ends and over which they are to be *clinched*.

A bolt which is to be unfastened occasionally may be secured either by means of a screw and nut, or by means of a pin or wedge, called a *forelock*, passing through a hole in the end of the bolt. The screw and nut, if properly proportioned, may be made nearly, though not quite, as strong as the body of the bolt; the forelock is not more than half the strength.

Copper and *yellow metal* are the only suitable metals for the fastening of outside planking. Where such bolts are used throughout, at least *two-thirds* of them should be driven through and clinched; the remaining third may be short bolts, called *dump-bolts*, stopping in the frame timbers.

Every butt in the outside planking should be fastened with two bolts, one of which should be driven through and clinched. Wherever important fastenings are made, all bolts should go clear through and clinch. The heads and rings of the bolts should be *counter-sunk* in the outside planking. A certain amount of *drift* should be given to each bolt.

Treenails when driven are clinched, as it were, by *caulking;* that is, two, three or four cuts, according to the size of the treenail, in the form of a cross, triangle or square, are made in its ends with a chisel, and are then caulked so as to spread the ends.

Two-thirds of the treenails should pass through both skins; the other third may be short like the dump-bolts.

Screw treenails having a screw thread cut in them have been used in England and Scotland.

In iron ships, plate-iron decks or parts of decks, such as waterways, stringers and diagonals, are riveted to iron beams. (See fig. 58.) The deck-planking, or flat of the deck, is bolted to iron beams with galvanized iron bolts.

When the beams are of timber, the planks are usually fastened to them with *deck-nails*, two to each strake and beam—which nails, for the *weather decks* or exposed decks, are of mixed metal, and for other decks, of iron. Treenails are frequently used for the same purpose.

CHAPTER XIII.

ON COMPOSITE SHIPS.

THE principal object in building *composite ships* is to combine the durability and small friction of copper sheathing upon a wooden bottom with the greater strength, lightness, simplicity and cheapness possessed by an iron frame.

A principle requiring special attention in composite ship-building is, that every piece of iron must be completely *insulated*, or cut off, from electrical communication with any piece of copper or its alloys; otherwise the iron will be rapidly corroded.

One thing should be kept in mind in composite ship-building, which is, that while the expansion of wood by heat is insensible, that of iron is about $\frac{1}{800}$th of its length for the difference of temperature between the freezing and boiling points of water. This fact leads to the belief that it is better, in composite ship-building, to make all pieces which lie fore and aft of wood, and all those which lie athwartships or diagonally, or which stand upright, of iron, rather than to combine pieces of different materials in positions parallel to each other.

The system of composite ship-building most generally practiced is that known as Jordan's system, in which the whole outer skin, including keel, stem, stern-post and planking, is of wood, arranged as in the skin of an ordinary wooden ship; and the framework inside of the skin—including frames, beams, keelsons, stringers, shelf-pieces, water-ways, hooks, transoms, diagonal braces, etc.—is of iron, arranged nearly as in an ordinary iron ship, "*channel*" or trough-shaped iron being used for the frames.

The bolts which fasten the skin to the frames are of iron, generally "galvanized" or coated with zinc; and their outer ends are countersunk in holes of such a depth that the iron bolts can be electrically

insulated from the copper sheathing by plugging the holes with pitch or other suitable non-conductor of electricity.

In the second method, known as MacLaine's, there is a complete water-tight inner skin of iron plating, with its internal framing, viz., beams, stringers, keelsons, bulkheads (complete or partial), stanchions, platforms, etc., of iron also.

Outside the inner skin are riveted transverse iron frames. Into each alternate space between the iron frames is fitted a wooden frame, which is bolted to the two contiguous iron frames with fore-and-aft galvanized iron bolts. It projects nearly half its depth outside of the iron frames. Outside of the wooden frames is a complete wooden skin (including keel, stem, stern-post and planking) fastened to the wooden frame with treenails or mixed-metal bolts. The apron, inner-post and deadwood are inserted between and bolted to angle-irons, which are riveted upon the inner skin. The outside of the inner skin is coated with cement, pitch or paint before putting on the wooden frame or skin.

The spaces between the wooden frames are ventilated artificially; though in the armor-plated parts of ships of war they may be filled up solid with the wood. Any water which may get through the outer skin lodges in the spaces between the wooden floors, whence it is removed by pumping. To diminish, when required, the weight and cost of the wooden framing, every alternate wooden frame may be omitted and replaced by a bent plank of *teak* or other sufficiently strong timber fastened to the outer skin only.

In another system,* the ship has a complete inner skin of iron, on the outside of which are riveted transverse iron frames of a Z-shaped section. The spaces between the frames are filled up tight with timbers shaped like the frame timbers of a wooden vessel, rabbeted into each other and bolted with fore-and-aft bolts to each other and to the iron ribs. Between these filling timbers and the iron skin is a layer of pitch. The filling timbers project beyond and completely cover the outer flanges of the iron ribs, and the seams between them are caulked, and have a groove running down the outside edge of each of them.

Outside the filling timbers is a wooden skin consisting of a keel and fore-and-aft planking laid and caulked in the usual way, and

* Known as "Heins'."

fastened to the filling timbers with mixed-metal nails and bolts. Any water which penetrates through the seams of the outer skin is caught by the grooves along the seams of the filling timbers, runs down those grooves into a limber or water-passage cut in the upper side of the keel and is drawn from that passage by a pump. The beams are of iron, connected with the inner skin by means of *gussets* or knees.

Another system* consists in imbedding iron frames between two wooden skins, and is as follows: There are two complete wooden skins, each laid fore and aft; the outer skin consisting of keel, stem, stern-post and planking, and the inner skin of keelson, ceiling or inner planking (made of planks or timber, as may be needed for strength), shelf-pieces, water-ways, etc., so that *all* the longitudinal pieces in the ship are of *timber*.

The transverse pieces are of iron, and consist of ribs or frames and deck-beams. The wooden skins have a layer of tarred felt between them, and are fastened directly together with copper or mixed-metal bolts or wooden treenails, so that their seams break joint with each other, and they hold the iron ribs between them imbedded in grooves in the inner skin; thus those ribs are not weakened by rivet holes, and are not in contact with electro-positive metal. Both skins are caulked, the inner one both inside and out; and the strakes of the inner skin (including keelson, shelf-pieces, etc.) are coaked and bolted to each other edgewise.

Lastly, there is a system† in which both frame and skin, up to the load water-line, are built of wood, while both frame and skin above that are built of iron. The iron frames terminate at their lower ends in broad forks or saddles, which sit upon and are fastened to the wooden parts of the sides.

* By Capt. Skinner, R. N.

† Known as "Feathers'."

CHAPTER XIV.

CAULKING IRON AND WOODEN SHIPS—PROTECTING THE BOTTOMS OF WOODEN AND IRON VESSELS.

CAULKING the seams and butt-joints of an *iron ship* is performed by means of tools like blunt chisels; these are of two kinds—the blunter tool for the butt-joints, and a less blunt tool for the seams. With a hammer and one of these tools the caulker makes an indented groove parallel to and about an eighth of an inch from the joint to be caulked; at the seams, that groove is on the edge of the overlapping plate; at the butt-joints, on the outer surface of the plate, on each side of the line in which the plates meet. The effect of this process is to force the particles of iron toward the joint, and thus close it tightly. Water-tight iron bulkheads and platforms are caulked like the outside plating.

In a *wooden ship*, caulking is performed, first on the treenails, and then on the planking, by driving into the seams *threads* or layers of *oakum*. Oakum is made of *junk* picked to pieces.

The seams of the planking, in order to receive the oakum, require to be open to the extent of about $\frac{1}{20}$th of the thickness of the plank. A gauge for the proper width of opening is made by setting the arms of a jointed rule to the angle produced by ½-inch of opening between them at a point 10 inches from the joint, when the opening between the arms of the rule at a distance from the joint equal to the thickness of plank will show the proper width of opening for the seams at their outer edges.

Seams that are closer than the proper width are opened or *reemed* by the *reeming-irons* and *beetles*. This is considered also a test of the sufficiency of the fastenings; and should they prove insufficient, so that planks are *started* by the opening, new fastenings are at once

to be put in. After each seam has been opened or reemed, the proper number of threads of oakum are forced in one after another by means of the *caulking-iron,* an iron wedge driven by the beetle or mallet; beginning usually with spun yarn or with *white oakum,* and finishing with *black oakum.*

The following table shows the number of threads of oakum used in caulking the seams of planking of different thicknesses:

Wales and Bottom Plank.

Thickness, inches..............	1,	2,	2½,	3,	4,	5,	6,	7,	8,	9,	10.
Oakum, double threads.......	1,	2,	3,	4,	5,	6,	8,	10,	11,	12,	13.
Spun yarn, single threads....				1,	2,	2,	2,	2,	2,	2,	2.

Topsides and Water-ways.

Thickness, inches............................	2½,	3,	4,	5,	6,	7,	8,	9.
Black oakum, double threads............	2,	3,	4,	5,	7,	9,	10,	11.
White oakum, double threads............	1,	1,	1,	1.				

Gun Decks.

Thickness, inches..	3,	4.
Black oakum, double threads....................................	2,	3.
White oakum, double threads....................................	1,	1.

Spar or Weather Decks.

Thickness, inches...	2,	2½,	3.
Black oakum, single threads.................................	1,	2,	2.
White oakum, single threads.................................	1,	1,	1.

The number of threads for caulking the side and bottom may be calculated by rule, as follows:

Take the nearest whole number to once and a quarter the thickness of plank in inches.

After the oakum has been driven in, it is further compressed by means of a tool called a *making-iron* or *horsing-iron,* held by one caulker and struck with the beetle by another: this is called *horsing-up.* The seams are then *payed* with melted pitch; and sometimes the seam is filled up flush by laying in a thread of spun-yarn.

Weather decks of merchant vessels and yachts, and poop decks of

men-of-war, are sometimes payed with *marine glue*—a solution of *caoutchouc* and *shellac* in *naphtha*.

The opening and caulking of one seam tends to close the seams near it; so that although some of them may have previously been above the proper width, they may still require to be opened before caulking.

The opening and caulking of seams require careful superintendence, to see that the seams are really opened to the bottom, and not merely notched into shallow grooves; and that the oakum is really driven home to the bottom of the seam, and not *choked* or wedged into a mass near the surface, leaving the bottom empty.

Butts and the vertical scarphs of the keel are caulked like seams; and so are any *rents* or *shakes* that may occur in the planking.

In caulking decks made of *fir* the operations of reeming and horsing-up are generally omitted, because of the softness of the wood.

Protection of wooden and composite ships.—The bottoms of wooden and composite vessels, up to the water-line and sometimes a little higher, are usually protected by copper or mixed-metal *sheathing*, and their sides and upper works by paint.

The bottoms of ships, before being sheathed with metal, are payed over with pitch or tar. Small vessels for the coastwise trade are sometimes payed with pitch or tar only, sometimes coated with verdigris composition, instead of being sheathed with metal.

It is usual to launch a vessel before sheathing her, performing the sheathing process afterward in a dock. Some merchant vessels make several voyages before being sheathed, the idea being to soak and season the timber thoroughly, as well as to practically test the tightness of the seams and caulking.

The metal for sheathing is usually made in sheets of the following weights and dimensions:

Weight in *ounces*, per square foot...........	18	28	32
Thickness in inches (about).................	0.025	0.038	0.044
Length, inches.................................	48	48	48
Breadth, inches................................	20	14	14

Sheets are named according to the weight in ounces per square foot; 32-*ounce sheathing* is used for the bows, and for parts *between wind and water*; 28-ounce sheathing for the rest of the bottom, and 18-ounce

sheathing for the lower side of the main keel, between it and the false keel. The sheets are put on in strakes running fore and aft, the *after* end of one sheet overlapping the *forward* end of the next, and the *lower* edge of one strake overlapping the *upper* edge of the *next below.* They are fastened on with mixed-metal nails called *sheathing nails.*

The rate at which the corrosion of copper sheathing goes on is extremely variable in different cases, ranging from less than an ounce to ten or twelve ounces per square foot in a year. The smallest perceptible rate of corrosion is sufficient, by scaling off the oxide, to keep the bottom free from barnacles and weeds.

Experiment has shown that sheathing the *entrance* of a vessel with copper produced a diminution of the friction to a little more than one-half of that on a *painted surface,* while sheathing the *run* produced no sensible diminution whatever.

The sides of the ship above the sheathing, and the other woodwork should receive *three* or *four* coats of paint. *All* wood should be thoroughly *dry* when painted.

Protection of Iron Ships.—The process of galvanizing or coating with zinc forms a very efficient protection for iron against oxydation in sea water as well as in air. To coat iron plates with pitch, drying oil and paint has also considerable effect in protecting the plating against oxydation, especially if the iron is coated with oil *while hot* and afterward painted.

The paint used should be suoh as will not itself oxydize the iron; *red lead* is therefore objectionable, since it contains a large proportion of oxygen combined with lead; and as lead is *electro-positive* to iron, the oxygen tends to quit the lead and combine with the iron.

Zinc paint has a good effect, as zinc is *electro-negative* to iron. The iron-work of ships should receive at least three coats of paint outside and two inside, and care should be taken to procure good zinc paint and avoid the use of the white powder of barytes (heavy spar), which is a cheap imitation of oxide of zinc, and though without injurious chemical effect to iron, crumbles and peels off after drying.

Mere protection against oxydation has no effect in preventing iron ships from growing foul by the adhesion of shells and sea-weed; for that purpose a coating is required that shall peel off by slow degrees, carrying the barnacles away with it, and shall neither be too durable,

which would enable the barnacles to adhere, nor too perishable, which would cause it to be too soon worn out and lead to too great expense for its renewal.

Copper and yellow metal have these properties exactly, but they cannot be directly applied to an iron ship, because they are electro-positive to iron and cause it to corrode rapidly. Various compositions have been used, some with more or less success, as lime soap, amalgam of mercury and zinc, paint containing metallic copper in powder or red oxide of copper, *insulated* from the iron by the oily matter of the paint, etc.

To enable iron ships to be sheathed with copper or yellow metal it is necessary that the sheathing be insulated from the iron. One method, by Mr. Grantham, is as follows: Outside of the iron skin are riveted angle-iron ribs whose projecting flanges are of a dove-tail shape in section. An equal weight of iron is saved in the inside framing. The iron skin is then coated with pitch, and the spaces between the dove-tail flanges are filled by packing and wedging into them short pieces of plank. The outside ribs with their wooden filling rise to a short distance above the water-line, and the upper edge of the filling is guarded by a longitudinal angle-iron. The outer surface of the fillings having been payed with pitch, a complete wooden sheathing, about 1½ inches thick, is put on and fastened to the filling-pieces with mixed-metal nails, which should not pass through those pieces.

The wooden sheathing is then pitched and is sheathed with copper or *Muntz metal* in the usual way; care being taken to keep the metal sheathing two or three inches from any exposed piece of iron.

During some recent experiments (1864) in England, it was found that *zinc sheathing upon iron* lost about .002 inch of its thickness by six months' exposure to sea water, and remained free from shell-fish and sea-weed like copper and yellow metal.

CHAPTER XV.

GENERAL FITTINGS OF THE HULL—RUDDER, WHEEL AND STEERING GEAR—ANCHOR FITTINGS AND CAPSTAN—PUMPS—VENTILATORS—BOATS—INTERNAL ARRANGEMENT OF A SCREW FRIGATE.

First in importance is the *rudder*, which, when of iron or steel, usually consists of a frame, covered on both sides with flush-jointed plating, the two layers of plating being riveted through the frame to each other with rivets counter-sunk at both ends, and also riveted at their seams to *covering-straps* inside.

The foremost piece of the framing is called the *rudder-stock;* its upper end, called the *rudder-head*, is cylindrical, and rises through the cylindrical *rudder-port*, and through a vertical tube or *casing* having a *stuffing-box* at the top, into the stern of the vessel. Its lower end, or *heel*, usually forms a pivot, turning in a hole in the *skeg*, or projecting after end of the keel; its intermediate part is square and (except in the *equipoise rudder*) is hinged by pins, called pintles, fitting into eyes, called *braces* or *gudgeons*, to the stern-post or to the rudder-post. The aftermost part of the framing is curved to the shape of the after edge of the rudder, and is usually welded, at its upper and lower end, to the rudder-stock. In fitting iron rudders it is usual for one or two of the eyes or braces to have holes for the pintles drilled only partially through them. Into each hole is fitted a steel pin with the upper surface spherical. The corresponding pintle is fitted with a steel pin having its lower surface spherical. When the rudder is shipped its weight is borne at the points of contact of these spherical surfaces, so that the friction is very small.

A *wooden rudder* consists of an assemblage of pieces of timber coaked and bolted together, like those of the framing of the stem and stern-post. Fig. 93 (*a*) shows the arrangement of the several pieces. The dotted line XX is the axis of motion of the rudder, being the common axis of all the pintles and braces and of the rudder-head.

MM is the *main-piece*, usually of oak or other timber of equal quality. Its upper end is cylindrical and is the *rudder-head*. The shoulder, C, where it is in contact with the head of the stern-post, is conical, and at the small end of the cone is the upper pintle. The pintles are marked P. The foremost piece of the rudder is frequently of *elm*, and the other pintles are fitted into scores in it. The form of the after part of the rudder is given by pieces AA, usually of *fir*. At the *heel* of the rudder is the *sole* piece, S, usually of elm, lightly fastened, so that, like the false keel, it may be knocked off if the ship takes the ground. Fig. 93 (a) is a horizontal section of the foremost edge of the rudder and the aftermost edge of the stern-post, SP, showing how they are beveled or *bearded*, so as to admit of the helm being put over either way to the usual greatest angle of 42°; and how the shoulders of the pintles and the wood above and below them, having cylindrical surfaces described about the axis of motion, X, fit into a cylindrical hollow in the stern-post.

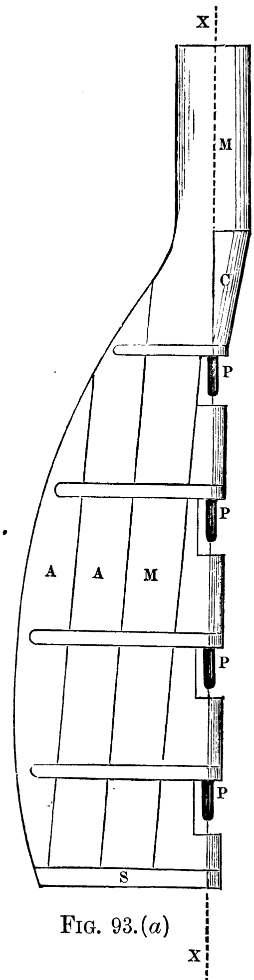


FIG. 93.(a)

Wooden rudders are sheathed with copper or yellow metal. Before the rudder is hung, the braces on the stern-post are adjusted to their correct positions by passing through them a perfectly straight, cylindrical wooden rod of the same diameter as the pintles.

To keep the rudder from *unshipping*, a *wood-lock*, d (fig. 94), is used, screwed upon the stern-post or rudder, and fitting into a score a little below the upper pintle.

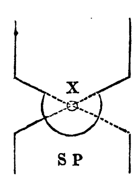


FIG. 93.(b)

Besides the rudders above described, there is the *equipoise rudder* (fig. 96), for

long screw-ships, and "*Lumley's*" *rudder.* Fig. 94 shows the ordinary rudder of a screw frigate of "Wabash" class. Fig. 95 is the *yoke.* The arrangement for tricing up the screw is also shown. B is a bar to which the rudder-chains are attached, the bar giving an extra leverage. AA (fig. 94) are pintles and their braces; C, the *gudgeons* and their braces; H, hole for use in shipping; *d*, the wood-lock.

The arrangement of the *wheel, wheel-ropes, tiller,* and *spare tiller* is shown in fig. 97.

A is the rudder-head; AT, the tiller, having a pair of single blocks fitted to its forward end; *kk* are eye-bolts at the side, to which the *standing part* of the wheel-ropes are made fast. The wheel-ropes, F, are rove as in the sketch, and made fast to the *barrel of the wheel,* C, on its upper side. The total number of turns is either 5, 7 or 9, so that from $2\frac{1}{2}$ to $4\frac{1}{2}$ turns of the wheel are required to put the helm hard over either way. The length of wheel-rope or chain wound on the barrel is about double the length of the arc through which the end of the tiller, B, is put over; and the effective diameter of the barrel (being = its actual diameter + diameter of rope or chain) is adjusted accordingly. (This refers to a single purchase.)

Wheels, WW, range from 3 to 6 feet in diameter and are usually made of mahogany strongly framed and bound with brass. The rudder must be so connected with the wheel that, in putting the helm over, the *lower* rim of the wheel shall be moved in the opposite direction to the rudder; that is, in the same direction with the tiller, which points forward. Hence, when the tiller points *forward,* the wheel-ropes pass *over* the barrel first; when it points *aft, under* the barrel. The diameter of the barrel should be made *less* in the centre, so as to avoid slack wheel-ropes. DD are the wheel *standards.*

Screw ships, having a screw aperture or trunk, usually have a *yoke* (fig. 95) instead of a tiller.

There are many patent arrangements for steering ships as well as appliances for making use of the power of steam for this purpose. None are thought to be as effective and simple, for men-of-war, as the old-fashioned tiller, wheel and wheel-ropes. (Figs. 97 and 98.)

Description of a tiller thus fitted.—Fig. 98 is a section showing the head of the rudder; *a* being the centre and centre line of the pintles; *b*, position of the blocks at the end of the tiller to receive the ropes, the

Scale, ⅛ of an inch to 1 foot.

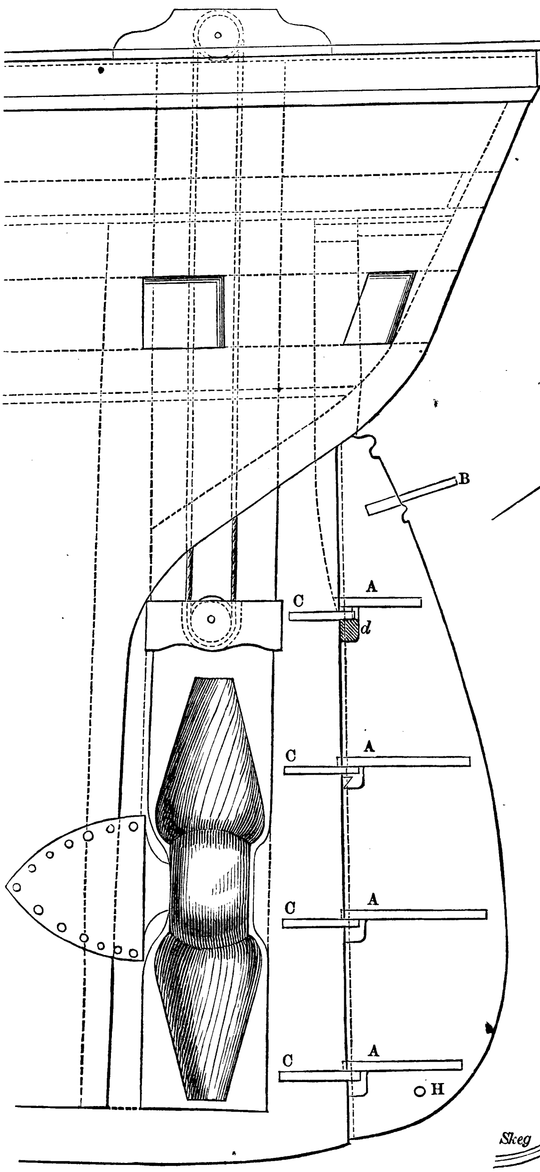
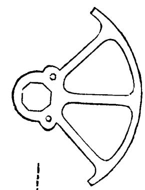


Fig. 94.

Fig. 95.



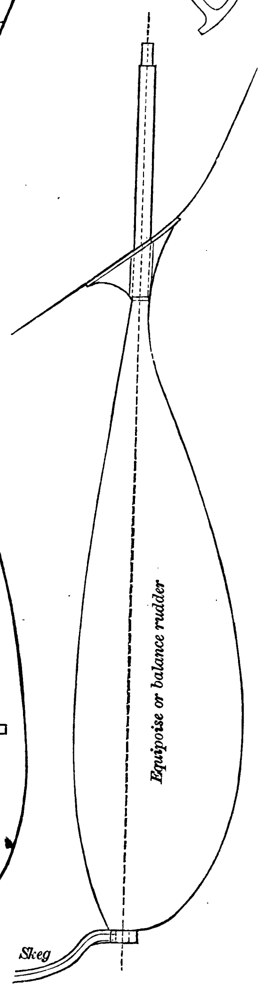


Fig. 96.

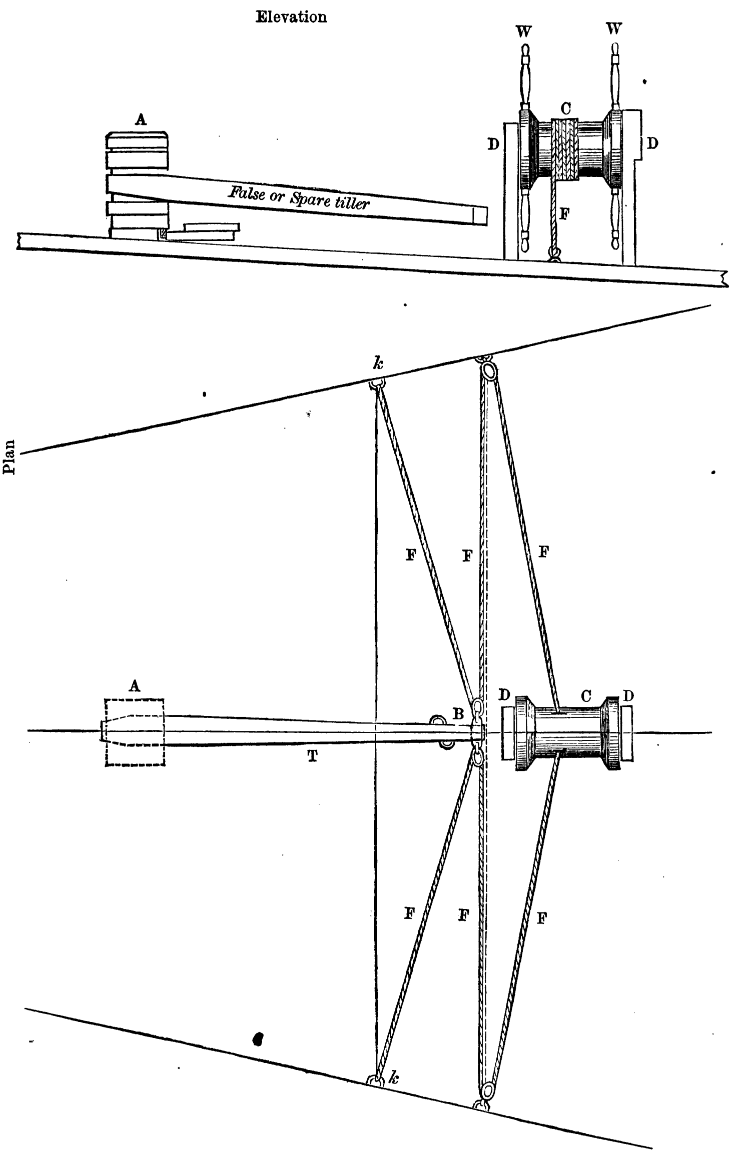


FIG. 97.—*Sketch of the Steering Wheel.*

tiller *ab* being amidships. Divide the distance *ab* into three equal portions, of which *bc* is one, having previously swept the tiller down to describe the circle *bmd*. The point *c*, squared athwart the ship to meet the circle described by the end of the tiller at *d*, will give the position for the standing part of the rope. The point *f* is set off $\frac{1}{12}$th of the length *ab*, on the line of the tiller from *b*, and squared across the ship; while *fe*, taken as $1\frac{1}{4}$ of *cd*, will give the point for the tiller-block at the side of the ship. These points cause the rope, rove through blocks placed at them, to move the tiller through an angle of 45° from the midship position, without any slack. In some ships the part *b* slides in and out on an iron tiller, so as to be always at right angles to the strain.

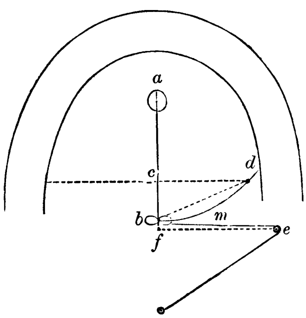


FIG. 98.

Among some of the most important internal and external fittings of a ship are the means by which the anchors and chains are supported and worked. The following sketch shows a section of a frigate's bow with the anchor supported from the cathead. (See fig. 99.)

A, fig. 99, berthing-rail, for safety to the men when they are out in the head, the flat or platform of which is on a level with the main rail (B).

B, main rail, to fashion out the head and afford an enclosed space for the accommodation of the crew.

C, middle or small rail for the exterior appearance of the ship.

D, the lower rail, the after part of which (with a portion 6 or 8 feet on the knee of the head) is called the *upper cheek* and forms, by being bolted to the bows of the ship and to the knee of the head, a species of wooden knee supporting the latter. The after arm of this knee is shown in projection in the figure, and on the knee of the head is described its form and length. The moulding or breadth is usually at the throat $2\frac{1}{2}$ times the depth of the cheek. The fore part of D is called an "eking," the extreme end, M, shown by a scroll, being termed a "hair-bracket;" and this hair-bracket should, for symmetry of appearance, be placed rather below the shoulder of the figure-head.

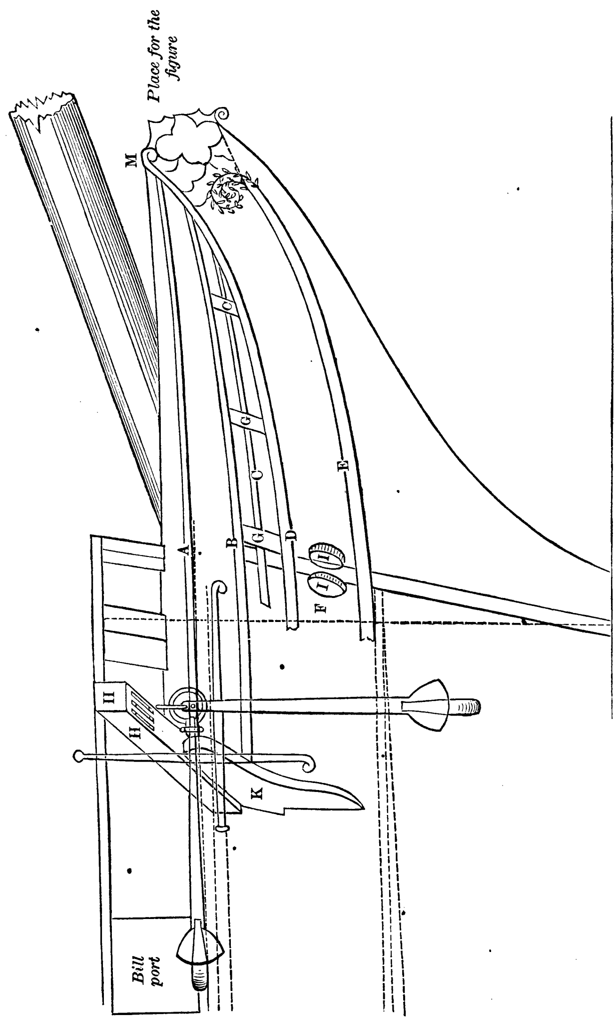


FIG. 99.—*Sketch of the Head of a Frigate.*

E, *lower cheek*, a wooden knee, as described for the upper cheek, and bolted also to the bows of the ship and knee of the head. At the knee of the head the bolts in the arms of these cheeks pass through similar knees on the opposite side.

F, bolsters of wood placed between the arms of the cheeks (D and E) where they come against the bows of the ship. These bolsters are worked to form beds for the iron hawse-pipes (I), which are put through the sides of the ship, and form the hawse-holes for the cables. The bolsters should slightly project over the moulding-way or breadth of the cheeks to form a protection to them. They are bolted to the side of the ship independently of the bolts which secure the hawse-pipes (I). Immediately forward of the bolsters a piece of wood termed a corner chock is usually worked, the intention being that the fore ends of the planks, called hood-ends, may, by its removal, be caulked without disturbing the hawse-pipes or taking down the bolsters, an operation attended with expense and loss of time.

The fillings between the cheeks on the knee of the head are of fir, and being intended solely for the appearance of the ship, are in many instances dispensed with.

G, timbers of the head, to support the middle and main rails. For a light and neat appearance the after one is placed to the rake or inclination of the stem; the next with 1½ inches more rake; and the foremost one with 1½ inches more rake than that, or with 3 inches more rake to it than the one at the stem.

There is a thin berthing of board placed between A and B; and over A a plank termed a wash-board is sometimes used.

H, cathead.

K, supporter or knee of the cathead.

Next in order comes the *capstan* (figs. 100, 101 and 102), a mechanical arrangement corresponding to the mechanical power of the wheel and axle.

Fig. 100. *Elevation of a double capstan, as sometimes fitted to frigates of the navy.*—In frigates, the upper barrel comes on the quarter deck, the lower barrel being on the gun deck, on which the hawse-holes are placed.

AAA, iron spindle extending from upper point A to the lower point marked A′. This spindle should be well forged, and should be of the best materials, the whole strength of the capstan depending

Scale, ¼ of an inch to the foot.

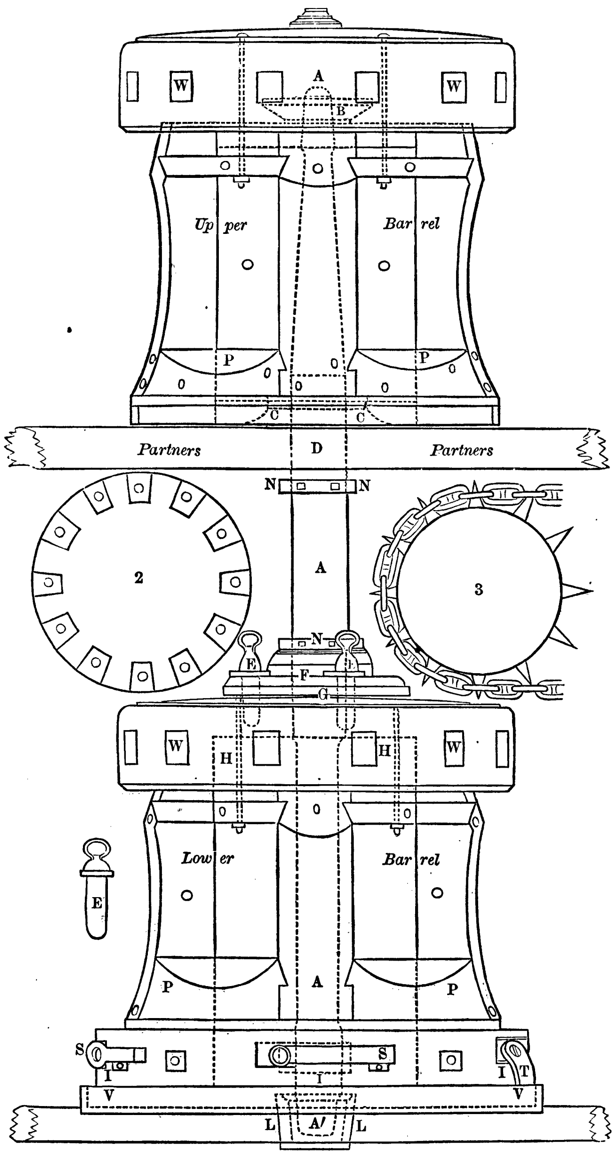


FIG. 100.

thereon; it is also placed in a turning lathe, by which the cylindrical form requisite to make it work accurately is ensured.

B, hoop and plate on the tenon of the upper barrel, by means of which the barrel is united to the spindle A at the upper part.

C, a similar plate and hoop for security of the lower end of the upper barrel of the capstan.

D, hoop in the partners of the gun deck working in a metal bush or socket, thus forming a support for the spindle A to work in through the partners of the deck.

E, drop-pins to connect the upper and lower capstans, as the spindle A passes through the lower capstan without being united to it, or, in other words, the lower capstan has free play or movement round it.

F, upper connecting plate, which is strongly secured to the spindle A.

G, lower connecting plate, which is let firmly into the trundle-head H; in F and G corresponding holes are made to receive the drop-pins E. To attach the lower capstan to the upper one, or to the spindle A, the drop-pins, E, are let down through the corresponding holes for their reception in the connecting plates F and G, by which the trundle-head of the lower capstan, and hence the barrel, is made one with the upper capstan. This power of connecting and disconnecting the two barrels admits of using the capstans at one and the same time for separate purposes.

I, pall-head; receiving the palls or stops to prevent the recoil of the capstan.

S, a pall or shore of iron, swiveling on a bolt, which is shown up, or in the position in which it is placed when not required for use.

T, a pall down and in use; the lower end being dropped into the pall-rim V against a stop formed in it.

V, pall-rim or ratchet, let down into the lower partners and bolted firmly to them; indeed, on the security of this rim the safety of the men at the bars mainly depends, and care should be taken in fitting it. The plan of the pall-rim is described by 2.

L, metal step or *cup* for the lower end of the spindle A to work in.

N, collars or stops on the spindle A; the upper one is necessary to keep the capstan from rising, which it prevents by its coming into contact with the partners D; the lower collar prevents the lower cap-

Scale, ¼ of an inch to 1 foot.

Elevation

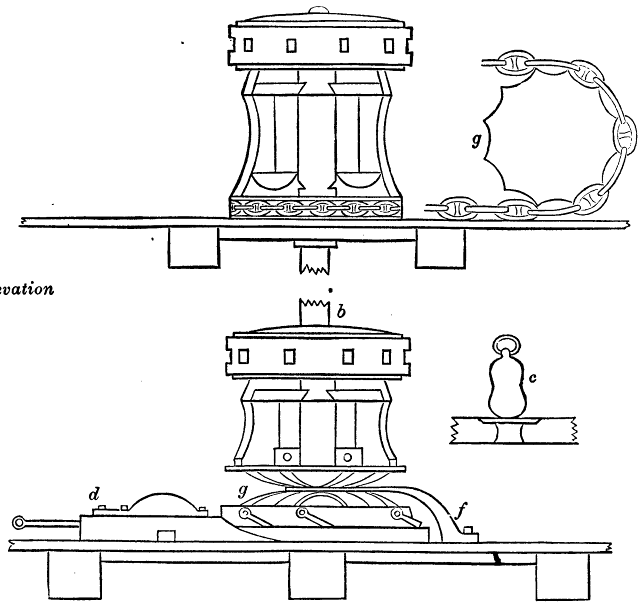


Fig. 101.

Plan.

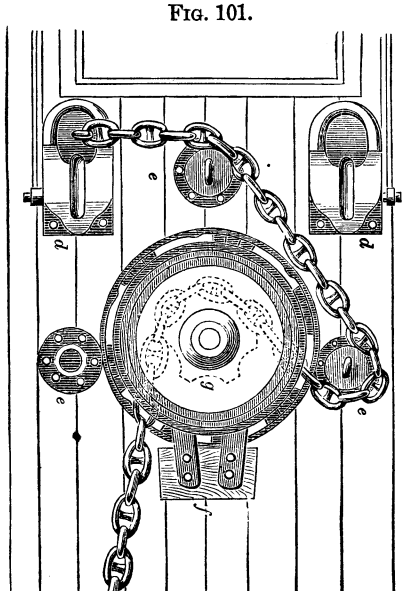


Fig. 102.

stan, when used separately, from rising, as it forms a stop to the upper connecting-plate F.

O, the whelps of the capstan; they are formed in a curve to give the surge required to prevent the turns of the messenger from rising too far up when a hemp messenger is used.

P, chocks placed between the whelps to steady them.

W, pigeon-holes to receive the bars which work the capstan.

The number of capstan bars is usually twelve, and their length varies with the rate of the ship. (See Book of Allowance.)

To set this machine in motion, a moving power (the ship's company) is applied to the bars of the capstan. The cable itself is not generally attached to the barrel of the capstan, but is connected with it by means of a rope or chain called a *messenger*, which passes round the capstan, and is made to unite itself firmly to the cable by *nippers*. When a chain messenger is used, the links of the chain messenger are sometimes worked over studs placed on the capstan, as shown by 3.*

Another style of capstan ("Brown's") now in use in many vessels, is shown in figs. 101 and 102, being intended to take the chain cable directly, without the intervention of a messenger.

In connection with this capstan is a patent arrangement for doubling the power.

b, elevation of the main-deck capstan with fittings at the lower part formed of iron, the ribs, *g* and *g*, acting like teeth to clasp the cable, similar to the sprocket-wheel of the common capstan when a chain messenger is used.

c, elevation of a friction roller, round which the cable passes, as shown on the plan, three or four being used and marked, *e*.

d, the controller for the cable.

f, the pointer.

h, the cable leading to the hawse-hole. The method of bringing it to the capstan may be traced on the plan; the links shown in dotted lines being those in contact with the ribs (*gg*) of the elevation.

The merit of this plan consists in not requiring the intervention of a messenger, whereby the hands required for passing the nippers, when a messenger is used, are saved.

* In the United States Navy the links of the iron messenger fit into sockets at the base of the capstan V.

The windlass used in small vessels is a capstan with the barrel worked horizontally, the power being applied by levers, which are shipped or worked in holes similar to those in the capstan head.

Pumps for discharging water from the ship's hold usually stand in compartments called *pump* wells, which extend from the ship's bottom to the lower deck, and sometimes to the upper deck. In iron ships, divided into compartments by water-tight bulkheads, there is usually a pump from 6 to 8 inches in diameter to each such compartment. Pumps draw the water from the *limbers* or water-channels and discharge it into the sea through the *pump-dales.* Pumps are now invariably made of metal, and are of endless variety, both as to construction and the mechanism by which they are worked, but for the most part they belong to one or the other of the three following classes:

1st. *Piston pumps,* in which a piston either moves up and down or to and fro in a cylinder or barrel, or revolves in a circular casing, the former being by far the more usual form.

2d. *Chain pumps,* which consist of a tube with its lower end dipping into the limber, and of an endless chain passing up the tube over a sprocket-wheel, and down another tube called the *back casing,* and carrying a series of circular discs which nearly fit the tube, yet not so closely as to rub against it. The sprocket-wheel is turned by means of cranks or winches on its axle, and the discs thus drive the water before them up the tube and into the pump-dale overboard.

3d. The *centrifugal pump,* consisting of a fan-wheel rotating within a circular casing, at a speed sufficient to produce in the mass of water within the casing an outward pressure intense enough to raise it from the level of the limbers to that of the pump-dale.

Of piston pumps are many varieties, as the *lifting pump, the sucking pump, the forcing pump* and *the double-acting force pump.*

In all sorts of pumps it is essential to economy of power that the passages traversed by the water should be as roomy, as short and as direct as possible, free from sudden contractions, sudden enlargements and sharp turns; and this requires special attention where there are valves.

The *efficiency* of good pumps, or proportion of useful work to total work, may be estimated as varying from two-thirds to four-fifths.

Pumps are frequently driven by steam-power, and the *main pumps* always so in steam vessels.

Tanks for holding fresh water, of which a small number only are now supplied to our cruisers, are built of iron plates, which should be *galvanized.* They are usually rectangular or about 4 feet square, and from 4 to 6 feet deep. They hold from 400 to 600 gallons, a *gallon* being .1604 of a cubic foot and weighing (imperial) 10 lbs.* Tanks are generally flat-topped and flat-bottomed, but some have the lower edge of the base tapered off, that they may fit into the bilge of the ship; hence they are called *bilge tanks.* Each tank has a *man-hole* and *lid.*

Ventilators are now generally made of copper or galvanized iron, and have large, bell-mouthed hoods, which are faced to windward at pleasure. They are especially necessary in the engine and fire-rooms of steamers to promote a circulation of air below. Some ventilators have rotary tops, which revolve and force a current of fresh air down below, while a tube on the opposite side of the deck carries up and off the foul air of the lower decks.

Where iron and steel masts are used, they perform the work of ventilators.

Boats.

The best kind of timber for building boats is the same as that best suited for the parts of ships alternately wet and dry. Oak for frames—cedar and pine for planking. Boats are distinguished into *carvel-built, clincher* or *clinker-built* and *diagonal-built* boats.

In all three of these styles of boats there is a keel, stem and stern-post rabbeted to receive the planking, as in a ship; the stem is scarphed and the stern-post tenoned to the keel.

I. *Carvel-built* boats have frames, each consisting generally of a floor and two futtocks; the floors are scored down over the keel and fastened to it with bolts in the larger and *nails* in the smaller boats. The frames are sided, moulded and trimmed to their proper bevelings like those of a ship, and are kept temporarily in their shapes and places by cross-spalls, ribbands, harpins and shores. The planking consists of strakes laid fore and aft with *flush seams,* like those of a ship; they are usually fastened with two nails in each timber of the frame. The strakes first put on are the lowest or *garboard strake,* and the uppermost but two, called the *binding strake.* Above the

* The standard United States gallon, 0.133 cubic feet, or 8.338 lbs.

binding is the *landing strake;* the *gunwale* rests on the timber-heads and covers the upper edge of the landing strake, and the uppermost or *sheer strake* has its upper edge flush with the top of the gunwale, and its lower edge overlapping the landing strake. The stern is usually strengthened by a *transom* and the bow by two *hooks.* Movable strakes above the gunwale are called *wash* strakes. The *thwarts* are the transverse plank keeping the sides together and asunder, like the beams of a ship. Some are fixed, others loose. The thwarts are spaced about 2 feet 10 inches from centre to centre in single-banked boats, and 3 feet in double-banked boats, and are secured to the sides with *knees.* Some boats have an inside planking or *foot-waling* in the bottom—others have movable *bottom boards,* others gratings.

II. *Clinker-built* boats are the lightest class for their strength and size; they are distinguished by the lower edge of each strake of plank overlapping the upper edge of the next strake below. They are not built upon frames, but upon temporary, transverse sectional moulds, two, three or four in number, which are fixed at their proper stations on the keel; the strakes are then put on, beginning with the garboard strake and bent to the figure given by the mould; each strake is fastened to the next below it by nails driven from the outside through the *lands* or overlaps. When two or more lengths of planks occur in a strake, they are scarphed to each other, the outside lip of each scarph pointing aft. The scarphs have a layer of tarred paper between, and are fastened with nails driven from the thin end of each piece. Toward the *hooding-ends* the strakes are *chased* into each other; that is to say, a gradually deepening rabbet is taken out of each edge at the lands, so that the projection of each strake beyond the next below it gradually diminishes, and they all fit flush with each other into the rabbets of the stem and stern-post. Floors, futtocks and hooks are afterward put in and fastened to the planking by nails driven from the outside and clinched inside.

III. In *diagonal-built* boats the skin consists of two layers of planking, with flush seams, making angles of about 45° with the keel in opposite directions.

They are built, like clinker-built boats, upon temporary transverse moulds. After setting up and fixing the moulds upon the keel, the gunwale, a shelf-piece and a series of ribbands are temporarily fixed on the moulds. The two layers of planking are then put on, bent to

fit the moulds and ribbands, and fastened to each other and to the keel, stem, stern-post, shelf and gunwale with nails driven from the outside and clinched inside upon small rings. The gunwale is then shored to keep it in shape; the moulds and ribbands are taken out, and floors, hooks, thwarts, etc., are put in, as in a clinker-built boat.

Internal Arrangement.—A full account of the internal fittings of a screw steamer of the first class will not be attempted in this work, which is an elementary one; but the following will give a general idea of the internal arrangement of a screw frigate of the first class, such as the "Colorado" or "Wabash."

The hold and decks are first sub-divided off into compartments by bulkheads; those in the hold should generally be water-tight.

Commencing forward in the *hold*, the first portion bulkheaded off is known as the block-room or *fore peek*, and is appropriated to the stowage of boatswain's and other stores. Next abaft this is the *fore magazine* for the stowage of a portion of the powder; abaft the after bulkhead of the fore magazine the foremast is stepped, and abaft this comes the forward shell-room. Next the forward bulkhead of the fore hold. This bulkhead, like other bulkheads in the hold, is of three-inch plank, or sometimes of half-inch boiler-plate iron, and should be water-tight. From this bulkhead to the after one of the fore hold is stowed, first, the water-tanks, and the size and number of these tanks should be just sufficient to stow without "*breakage.*" In a steam frigate of the "Wabash" class the space from bulkhead to bulkhead is twenty-five feet, and the tanks, each about six feet long, are stowed in lines of four each, so that there is no breakage. The two midship after tanks are called the receiving tanks, and receive the water fresh from the condenser. In many ships an apparatus for aerating the condensed water is attached to these tanks. Above the tanks in the fore hold is stowed part of the provisions.

Abaft the fore hold are the chain-lockers for the *bower* and *stream* chains, and immediately abaft the bulkhead, which is a heavy one, is the main coal-bunker, which communicates directly to the side bunkers, the whole space occupied by the coal enclosing the space occupied by the boilers and engines, and to a certain extent protecting them from shot in action. The coal in the side and main bunkers stows as high as the berth deck. Inside of the iron bulkheads form-

ing the side bunkers are, first, the boilers, and next, the engines. The boilers are generally multitubular, of Martin's patent (vertical tubes), though the horizontal tubular boiler with super-heater is deemed the best for these ships. The whole space occupied by engines, boilers and coal is sixty-six feet. The heel of the mainmast steps in a heavy beam supported by a forked stanchion over the shaft immediately abaft the after cylinder.

As far aft as the stern bearing and the after deadwood is a space enclosing the shaft, formed of double boiler plate, and known as the shaft alley; it is semi-circular, and just large enough to admit of the passage of one person on each side of the shaft.

Abaft the after engine-room bulkhead are the *sheet* chain-lockers; next, the main hold with its water-tanks and provisions (three tanks in a row fore and aft), occupying a space of twenty-two feet. Next, the after shell-room, abaft which is a space formerly called the *spirit-room*, but now appropriated to the stowage of miscellaneous stores in the paymaster's department. Next, the after magazine and its passage; lastly, the engineer's store-room, which brings us to the after deadwood.

Forward and aft over the hold, but below the berth deck, are decks extending a short distance, and known in the U. S. Navy as the *forward and after orlops*, though generally in foreign services called *cockpits*. Commencing with the forward one, the first space bulkheaded off is called the *paint-room*; the next, the *general store-room* or *yeoman's store-room*. Next, the forward sail-rooms; next the bread-rooms, the after part of which is terminated by the forward bulkhead of the fore hold.

In the after orlop, commencing at the after bulkhead of the main hold, come first the after sail-rooms; next, state-rooms for assistant surgeon, clerks and other cockpit officers; next, paymaster's store-room for clothing, etc.; after which come bread-rooms and navigator's store-rooms, with store-rooms for medical stores, marine stores, etc., etc.; finally, another large bread-room, which brings us to the after deadwood. The mizzen-mast steps in the after orlop.

Berth Deck.

Commencing forward on the berth deck, the first portion bulkheaded off is the sick bay; then the forward berth deck appropriated

to the crew. At the after part of this deck is a bulkhead enclosing the smoke-box and stack, with a wide passage on either side aft, occupied by various store-rooms. Next come the quarters of the warrant officers, with their mess-room and state-rooms; abaft which are the starboard and port steerages and mess-rooms occupied by the midshipmen and assistant engineers; finally, the ward-room bulkhead, abaft which are seven state-rooms on each side, with pantries, etc., appropriated to the use of the commissioned officers.

Main or Gun Deck.

This deck has no bulkheads, except those surrounding the engine-room and the cabin bulkheads aft. Commencing forward, first is the manger, bowsprit step, closets on either side, riding bitts (bower and sheet), galley and forward capstan. Midway between the main-mast and mizzen-mast the after capstan; finally, the cabin bulkhead and cabin.

Spar Deck.

The spar deck is flush, with the exception of a slight *monkey poop* and *rail* around the *propeller well.* There are two capstans on the spar deck.

CHAPTER XVI.

LAUNCHING—VARIOUS METHODS.

THE term *launch* is used to comprehend the whole apparatus for launching the ship, together with the *slip* on which she is built and its equipments. The slip has already been described (Chapter VI.), so that the apparatus specially connected with launching remains to be described. It may be divided into two principal parts—the *sliding-ways* or *slip-ways,* which rest on the floor of the slip and present a smooth upper surface; and the *cradle* or temporary framework which rests and slides upon the slip-ways, and supports the ship during the launch.

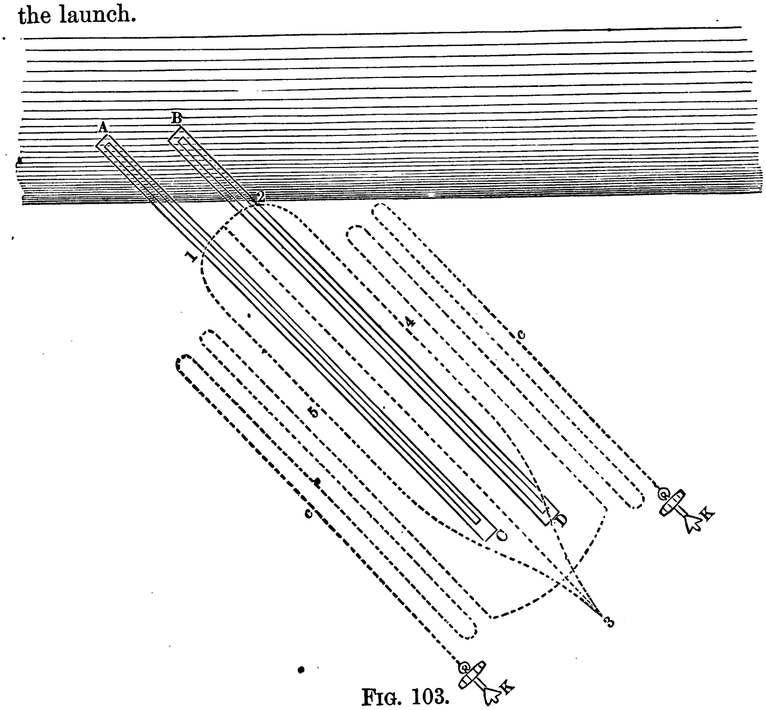
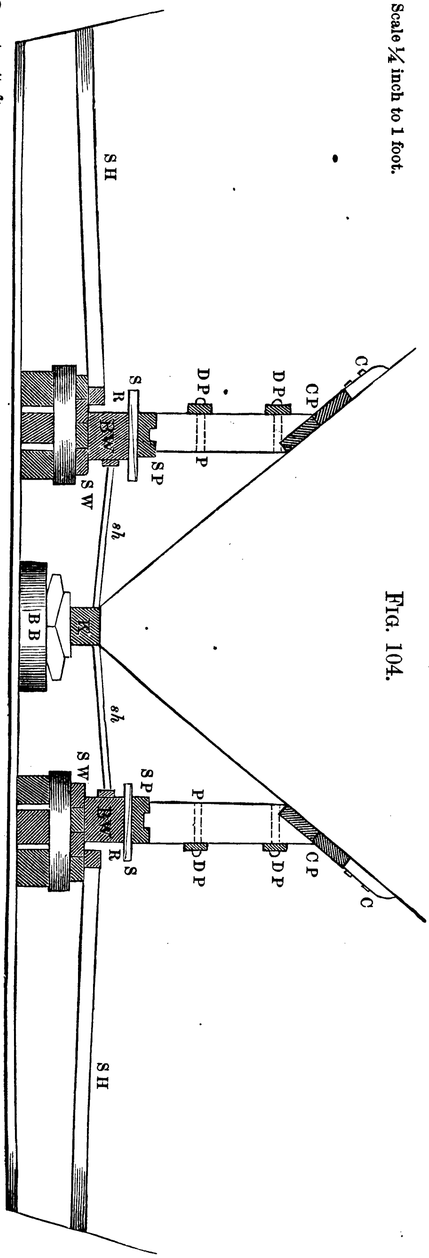


FIG. 103.

In fig. 103 AC and BD are a pair of slip-ways, and the dotted outline (1, 2, 3, 4 and 5) marks the position of the ship.

In the cross section, fig. 104, SW are the slip-ways; and the structure above them giving temporary support to the ship is called the cradle.

The *slip-ways*, SW, SW (also called *sliding-ways*), are a pair of parallel inclined platforms of timber, firmly founded on the floor of the slip, and kept steady in their positions by shores, marked SH. Their slope ranges from 1 in 12 for the smallest ships to 1 in 24 for the largest. The planks which form the upper surface of the slip-ways should have their *butt-joints* beveled so as to lean a little forward, in order to prevent obstruction in the event of the sinking of the plank of the slide at the fore side of a butt. The ordinary breadth of each slip-way for large vessels is from 3 to 4 feet. The best method, however, of adjusting their breadth is the following: the area of bearing surface of the *bilge-ways*, BW, or lowest pieces



Scale ¼ inch to 1 foot.

FIG. 104.

of the cradle upon the slip-ways should be such that the mean intensity of the pressure shall not exceed 50 lbs. on the square inch, giving about 45 inches of bearing surface for each ton of load. This is necessary in order that the pressure of the load may not force out the lubricating material from between the slip-ways and the bilge-ways. The usual distance of the slip-ways from each other, from centre to centre, is about one-third of the extreme breadth of the ship; but this may be varied according to circumstances.

Upon the slip-ways are bolted the *ribbands*, RR, figs. 104 and 105, so as to form two ledges to guide the cradle during the launch. Shores, marked SH, abut against the ribbands outside to keep them in their places.

When a ship is to be launched in a direction at right angles to a quay or to the water's edge, the lower ends of the slip-ways lie in one straight line perpendicular to the keel of the vessel. But when the vessel is to be launched obliquely to the water's edge, it is often convenient to make the lower ends of the slip-ways lie in a line parallel to the edge of the water, as AB in fig. 103—care being taken that the upper ends of the bilge-ways lie in a line parallel to the lower ends of the slip-ways, so that both bilge-ways may quit their bearing on the slip-ways at the same instant. (This is called *oblique launching.*) The lower ends of the slip-ways usually run into a depth of water, such that by the time the bilge-ways quit their bearing on the slip-ways, the ship shall be completely afloat with her forefoot clear of the ground.

But if, in order to launch a ship over a quay, or to save expense by using a short cradle, the bilge-ways are so designed as to quit their bearing before the ship is completely afloat, a block must be placed under water in the prolongation of the centre line of the slip to support the forward part of the keel and the forefoot during the latter part of the process of launching, after the bilge-ways have quitted their bearing on the slip-ways. That block is usually made of cast iron, covered with a malleable iron plate on its upper surface, to protect it against being cut into by the keel of an iron ship.

Cradle.—The base upon which the whole cradle stands consists of the two bilge-ways, BW, BW, fig. 104. The length of the bilge-ways for wooden ships is usually about five-sixths of that of the ship; though for iron ships about one-third of the ship's

length is enough. The extent of bearing surface has been already stated.

At the middle portion of the ship's length, where her floor is comparatively flat, she is supported upon the bilge-ways by the aid of pieces, called *stopping-up pieces,* laid horizontally, and formed at their upper sides to fit the bottom of the ship.

Before and abaft the stopping-up pieces, the ship is supported on the bilge-ways by means of upright or slightly raking square posts, called *poppets,* as P, figs. 104 and 105. The lower ends of the poppets are kept in their places by being *tenoned* into the *sole-pieces,* SP. The upper ends of the poppets abut on the bottom of the ship, and are prevented from slipping upward by the planks, CP; and these are kept steady by means of the cleats, C, screwed or bolted in a temporary way to the bottom of the ship. They may also be braced together athwartships by chains passing under the keel.* The poppets are braced longitudinally by means of *dagger-planks,* marked DP in figs. 104 and 105. When a short cradle is used poppets are seldom required. SS are the wedges, called *slices,* between the sole-pieces and the bilge-ways, by means of which the weight of the ship is lifted off the keel, K, and building-blocks, and caused to rest on the cradle alone. When the building-blocks are capable of being easily lowered the slices are unnecessary.

Fig. 105 is a side view of the cradle—ST being the stem of the ship, DS one of the two *dog-shores;* its lower end abuts against the upper end of the ribband of the sliding-way, and its upper end against the *dog-cleat,* DC, which is bolted to the side of the bilge-way. Below the dog-shore is a small block called the *trigger,* which prevents the dog-shore from falling till the moment has arrived for launching the ship. Care should be taken to give the dog-shore no more slope than is just necessary to enable the dog-cleats to clear the ribbands of the sliding-ways, lest the dog-shores should *trip,* or turn over backward, and the vessel be launched unawares. From three-quarters of an inch to one inch of freedom is left at each side between the bilge-ways and the ribbands, increasing gradually downward.

References to Figs. 104 *and* 105.

a, ground-ways of the slip, with a declivity of 1¼ inches in a foot..

* See fig. 107.

b, ticked line denoting the upper surface of the blocks on which the keel of the ship rests while she is building.

BB, section of the building-blocks. The inclination of these blocks from the horizon is 1 foot in 19 feet.

SW, section of the sliding-ways as composed of blocks and planks.

BW, section of the bilge-ways laid on the sliding-ways, the outside of the one bilge-way being apart from the outside of the other one-sixth the main or greatest breadth of the ship, together with the breadth of the main keel.

f, section of the bilge-ways lengthways.

R, ribbands (square pieces of fir), secured to the sliding-ways to prevent the bilge-ways from spreading or being forced out when the ship is being launched.

hh, inclination given to the sliding-ways, usually from three-quarters to seven-eighths of an inch to a foot.

ii, stopping-up amidships, composed of large pieces of fir.

PP, poppets or shores before and abaft the stopping-up pieces.

SP, sole-pieces or planks worked to receive the lower ends or heels of the poppets.

DP, dagger-planks to connect the poppets (PP) with each other, and unite them with the stopping-up (*ii*).

CP, planks worked to the bottom of the ship to confine the upper ends or heads of the poppets.

C, cleats to support the plank (CP). They are screwed to the bottom.

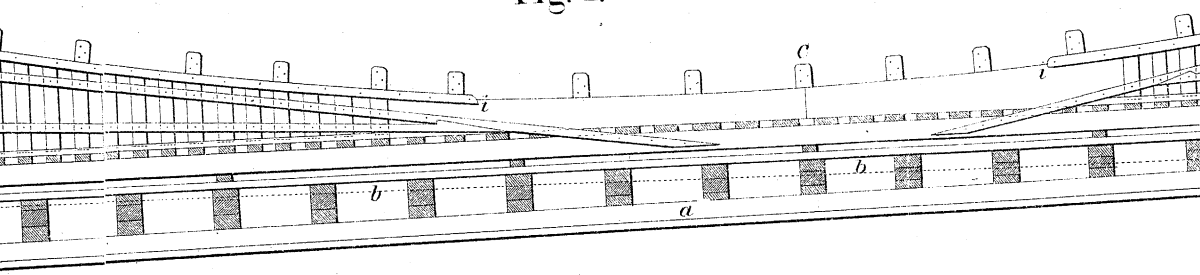
SS, slices or large wedges placed between the sole-pieces, stopping-up and bilge-ways, to set the launch to the bottom of the ship, and take the weight of the vessel off the building-blocks (BB).

SH, ribband-shores to support the ribbands and prevent them from spreading.

DS, dog-shore, with its heel resting against the fore end of the foremost length of ribband, and its head against the launching-cleat (DC) on the bilge-ways.

DC, launching or dog-cleat to receive the fore end of the dog-shore (DS). The under side of this cleat should be kept above the upper side of the ribbands (R), as in launching the cleat should pass over them.

Fig. 105



Scale 1/8 of an Inch to a Foot.

sh, shores placed from the ship to the bilge-ways to prevent them from tripping inward.

t, trigger placed under the dog-shore, and removed immediately previous to the launch of the vessel.

v, holes in the ends of the bilge-ways to receive ropes which are led on board the ship to secure the bilge-ways when the vessel is in the water, as the bilge-ways then usually float up from under her.

A much less expensive mode of launching than the foregoing is the method practiced in France and in many private ship-yards. The annexed figure (106) represents this method. The two pieces (*aa*)

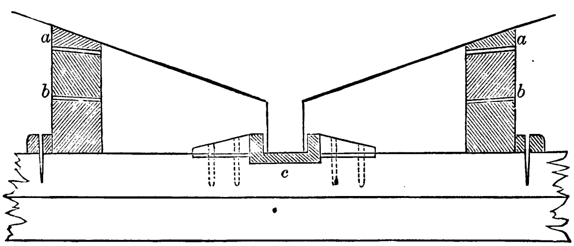


FIG. 106.

which are shown in the sketch as being secured to the ship's bottom are the only pieces which need be prepared according to this system for each ship, the whole of the remainder being available for each launch. A space of about half an inch is left between them and the *balk timber* placed beneath them, as it is not intended that the ship should bear on these balk timbers in launching, but merely be supported by them in the event of her heeling over. The ship is therefore launched wholly on the *sliding-plank* (*c*), fitted under the keel. Ships of 2600 tons have been launched in this manner without a single *cleat* or *ribband* of any kind upon their bottom, thus avoiding all the *making-up* of the slide-ways, except for about 60 feet in midships for keeping the ship upright. The centre-way was hollowed, and a round sliding-way fitted in it, and the keel was thus supported from end to end. This, therefore, may be considered to be the safest, cheapest and easiest mode of launching long, sharp ships.

If a ship is *coppered* before launching, so that putting her into dry-dock for that purpose becomes unnecessary, it is then desirable that she should be launched without any cleats attached to her

bottom. This method of fitting the launch is represented in fig. 107. It will be seen that the *principle* is the same as the first mode (fig. 104). The two sides of the cradle are prevented from being forced apart when the weight of the ship is brought upon them by chains passing under the keel. Each portion of framework composing the launch has two or more of these chains attached to it, and each chain is brought under the keel to a bolt (*a*), which passes loosely through one of the *poppets*, and is secured by a long forelock (*b*) with an iron handle (*c*), reaching above the water-line, so that when

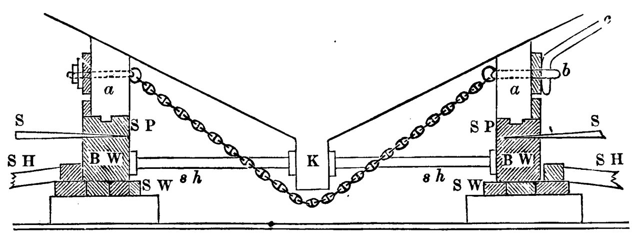


FIG. 107.

the ship is afloat it may be drawn out of the bolt. The chain then draws the bolt *a*, and, in falling, trips the cradle from under the bottom. There should be at least two chains on each side secured to the fore poppets, two on each side secured to the after poppets, and two on each side to the stopping-up, and this only for the launch of a small ship. In larger ships the number will be necessarily increased according to the weight of the vessel and the tendency that she may have, according to her form, to separate the *bilge-ways*. This tendency on the part of a sharp ship by a rising floor, or by her wedge-shaped form in the fore and after bodies, is great; but there is not much probability of a ship heeling over to one side or the other.

There is no valid objection to the cheaper and more ready method practiced in France of launching on the keel.

Preparations for Launching.—The slip-ways are completed and the cradles built and fitted up in their places a day or two before the launch is to take place, the ship still resting on the building-blocks and kept upright by props and shores. Shortly before the launch the bilge-ways are *turned out* of their places on the slip-ways, and the slip-ways and bilge-ways are payed over first with hard tallow

and then with soft-soap; the tallow to stop the pores of the wood and give it a smooth surface, and the soft-soap to lubricate that surface. The bilge-ways are then *turned in* again and the cradle fitted up as before, and the exposed parts of the slip-ways are covered with boards to protect them from dirt until the time for launching arrives. If the cradle has slices, they are then driven, so as to *set up* the cradle against the bottom of the ship and make it support her weight; if not, the same purpose is effected by lowering the building-blocks. Then the props and shores, which kept her steady when building, are removed, and the building-blocks are struck one by one from under her keel, commencing at the stern. Sometimes a few blocks are left under her forefoot to be tripped or overturned when she is launched. Meanwhile, if she is to be launched into narrow waters, her bower anchors (K) have been fixed in the ground in the ship-yard, as shown in fig. 103, and if necessary loaded to increase their hold; and her chain cables (*cc*) have been ranged alongside of her, so that their friction on the ground and the hold of her anchors may gradually stop her way after she has been launched. The cables should be triced up to keep clear of cradle, and *check-stoppers* put on in order to bring the ship up as gradually as possible.

Sometimes in large ships as an additional security the stern of the ship is buoyed up by immense casks or camels, slung with chains.*

If the ship, however, is to be launched into a wide space, her anchors are hung at the bows, and a tug at hand to tow her into the dock after she is launched. Her whole weight now rests on the bilge-ways, and she is kept at rest solely by the dog-shores. By *careful inspection* it should be ascertained that *all* is clear for launching.

Launching.—When the tide is high the triggers are removed, the dog-shores are struck down, and the ship is named as her forefoot touches the water.

Should she at first refuse to move, she may be started by the jack-screw or hydraulic press screw. After the launch the cradle floats up from below her bottom, and is hauled ashore by means of ropes attached to it for that purpose.

*** This was the case when the "Niagara" was launched; and the failure to take such precautions caused the "Roanoke" to "*break her back*" in launching.**

CHAPTER XVII.

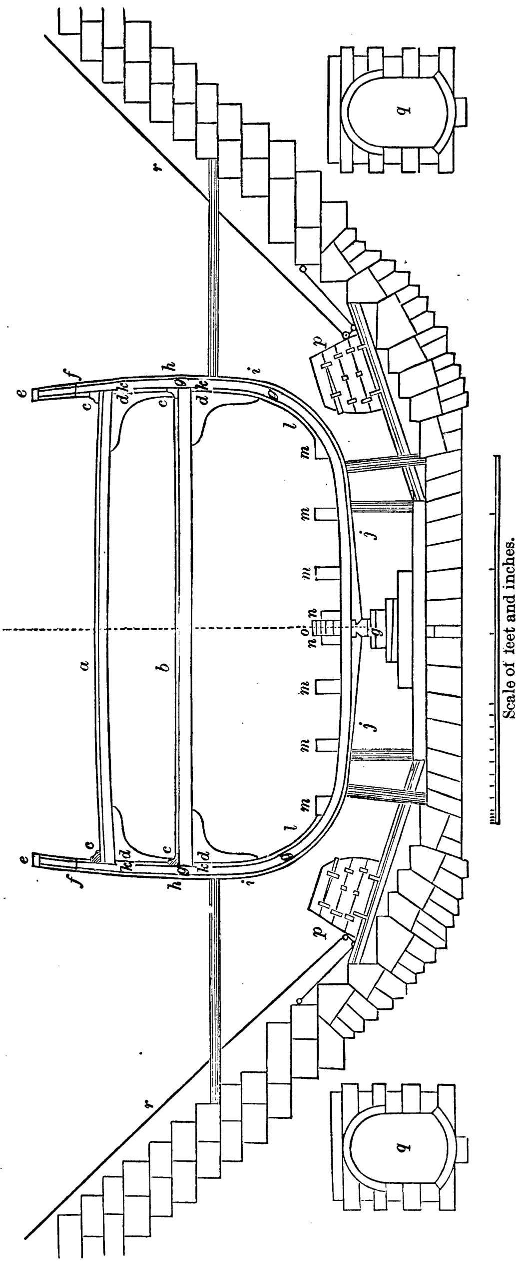
DOCKS—DOCKING SHIPS—HINTS ON REPAIRING WOODEN SHIPS.

SHIPS are frequently built and nearly always repaired in dock. There are several sorts of docks, as the floating-dock, dry-dock and wet-dock.

Where there is a regular and considerable rise and fall of the tide, excavations are made in the land near the water, faced with solid masonry, and generally having entrances fitted with gates or caissons, which serve either to retain or exclude the tidal waters, as desirable. Those on a large scale, as the London or Liverpool docks, which are kept full of water, are called wet-docks or basins, being in fact artificial harbors, in which vessels are always kept afloat while undergoing internal repairs, loading or unloading, fitting for, or being kept ready for going to, sea. Commercial wet-docks usually have "locks" (as in a canal) attached to them, so as to admit of the entrance and egress of vessels at any time of tide without losing more water than necessary. In naval wet-docks, the ships generally requiring as much water outside as in, one barrier in the form of a caisson is used, but which is seldom worked excepting at high water.

The *dry-dock* is both deeper and narrower. It is deeper because it is necessary to have more water in the dock at the time of docking a ship than at its entrance. This is for the purpose of gaining depth enough for the angle-blocks on which the keel of the ship is to rest, and is effected by having the floor of the dock somewhat below the low-water mark. Then, after closing the entrance, the dock is drained either by pumping or letting the water run off with the falling tide through channels called culverts. It is narrower, because when not water-borne the ship requires to be supported by shores, which, abutting on the sides of the dock, bear against those of the ship and are set taut by wedging. (Fig. 108.)

FIG. 108.—*Section of the Dry-dock at the Navy-Yard, New York, with the Midship Section of a Steam Sloop of War on the Blocks.*



a, Spar deck.
b, Berth deck.
c, Water-ways.
d, Hanging knees.
e, Main rail.
f, Portsill.
g, Ship's frame.
h, Wales.
i, Diminishing plank.
j, Bottom plank.
k, Clamps.
l, Bilge strakes.
m, Bilge keelsons.
n, Sister keelsons.
o, Main keelson.
p, Sliding bilge-blocks.
q, Culverts.
r, Line for hauling back bilge-blocks.

The *caisson*, or floating-dam, is a vessel whose length is equal to the breadth of the dock entrance. Both its ends are formed like the bow of a ship, and the keel is continued up each stem. It is ballasted and fitted with valves or *penstocks*, and so formed that when full of water and in its place across the entrance, the stem and keel fit accurately into a groove cut in the masonry on the sides and across the bottom of the entrance, the passage of water being thus prevented. When it is necessary to remove the caisson, the water is either run off at low water or pumped out; and as the entrance is widest at the top, the caisson on being floated up on the rising water becomes cleared of the grooves and is withdrawn.

The *patent slip* is an adaptation of the common slip to the purpose of repairing vessels. Carriages in number according to the length of the vessel, fitted with cog-wheels and working on corresponding racks, are run out under the bows of the vessel. When secured upon these she is hauled up either by capstans or steam machinery.

In order to take a ship into a dry-dock it is necessary to ascertain as nearly as possible the line of the ship's keel; then arrange the blocks in the dock to conform as near as may be to the line of the keel, always allowing the ship to settle a little in the centre. Let the ship be upright without heeling to either side; have the shores arranged on each side of the dock ready for use. Open the filling culvert gates, and when the dock is full open the turning gates; haul the ship into the dock and shut the gates. Place the ship in the centre of the dock, start the pumps, and as soon as the keel touches the blocks set up the horizontal shores by means of screws or wedges. As the water recedes from the dock, leaving the lower altars, other lines of shores must be placed and set up with wedges. As the water is pumped out the altars should be washed off, that the workmen may have a clean dock for their operations. When all the shores are placed and the ship properly secured go to work.

In docking large ships, such as heavy frigates, it sometimes becomes necessary to stop the pumps for a few moments in order to give the workmen time to get up a sufficient number of shores to secure the ship safely, which could not always be done with an ordinary crew of workmen if the pumps were kept at full speed.

In the *sectional floating-dock* the stability of the structure is secured by end-floats, which slide up and down in framework provided for the purpose. They also serve the purpose of ballast for sinking the dock to receive a vessel.

When a ship is to be raised upon this dock the water is let into the tanks, and the machinery put in motion to raise the end-floats, by which means the tanks are forced down to the proper depth to receive the vessel. The ship is then hauled in between the uprights, placed in the centre, and the end-floats are let down so that the tanks rise gently until the keel touches the blocks; the side horizontal shores are then placed to keep the ship upright, and the pumps are put in motion. When the tanks begin to press firmly against the keel, the bilge-blocks are drawn under the ship, and the pumping proceeds until the ship is lifted out of the water, care being taken to work the pumps in the different sections in proportion to the displacement of the parts of the ship resting upon them.

If the vessel is to be taken on shore by means of the basin and railway, the next operation is to bring the bottoms of the tanks in a plane, which is done by heavy bed-screws applied to any tanks which may be higher than the others. These screws are set against the ship's bottom, and their effect, when turned, is to force the tank down deeper into the water. When all the tanks are so arranged as to present an even uniform surface to the floor of the basin, the structure is hauled into the basin, the valves in the tanks are opened, and sufficient water is admitted to sink the dock and firmly ground it on the floor. The cradle is then placed under the ship, the hauling apparatus is applied, the engine put in operation, and the ship hauled ashore on the railway.

If necessary the ship may then be shored, as on a building-slip, and the cradle can be removed so as to give the workmen free access to all parts of the keel and bottom.

The *balance floating-dock* is provided with side chambers intended to answer the same purposes as the end-floats in the sectional dock; in these chambers are compartments into which water is raised for the purpose of sinking the dock to receive a vessel.

If a ship is to be raised and hauled on shore by means of the basin and railway, the cradle is first put in the dock, the dock is then sunk by opening the valves and by pumping water up into the upper side

chambers. When sunk to a proper depth, the ship is hauled in over the cradle and placed in the centre of the dock; the water is then let off from the upper chambers, which causes the dock to rise gently until the keel touches the blocks, when the horizontal shores are placed to keep the ship upright. The pumps are then put in operation, and as soon as the ship has a good bearing on the cradle the bilge-shores are drawn under her, and all the water is pumped from the dock. The structure is then floated into the basin; water is admitted into the dock to sink it upon the floor; the hauling-beams are now applied, the engine put in operation, and the vessel drawn on shore. As in the case of the sectional dock, if necessary, the vessel may be shored as on a building-slip, and the cradle removed to give the workmen free access to the keel and bottom.

If the vessel is not to be drawn ashore by the railway, the cradle is not used in the dock, but the ship's keel rests upon blocks laid on the floor of the dock for the purpose. The process of raising would be the same as in the other case.

Hints on Overhauling and Repairing a Vessel in Dock.

The ship having been placed in the dock and secured by the shores, as before described, if the repairs required are known to be extensive, the copper sheathing is taken off the bottom, and planks are split out fore and aft in those parts of the ship that experience has pointed out to be the most likely for decay to arise, such as the outside planking between wind and water, or immediately in the vicinity of her line of flotation, and in the *turn* of the *bilge,* where the *timbers* of the *frame* are very subject to rot from the wood being cut across the grain and the *heart* thus exposed to wet. The outside planking above water, immediately in the wake of the *channels,* will often be found defective from the strain brought on it by the shrouds causing the plank to open, or the *topsides* of the ship to work; while the timbers and planking in the immediate neighborhood of the *hawse-holes,* being subject to wet, are also places that require to be well overhauled. The water-ways, clamps and beam-ends are most exposed to the effects of water by leakage, a fruitful source of decay; and to prevent *unnecessary outlay* in the repairs the ship should be thoroughly

opened. *All* defects should be removed before any new work is allowed to take place, as most serious expense has been incurred—ships of war having been repaired that would have been taken to pieces had the defects of the ship been fully laid open in all parts before the first-discovered defects were made good. It is an evidence of sound judgment, in directing the repairs of a ship, to make a thorough search for defects, and totally remove them before any new materials are provided, much less worked into the ship. This method of proceeding presents another advantage in that the timbers of the ship are thrown open to the air for a time, and a check thus given to any incipient decay or production of fungus. When the repairs to be executed run to a great extent, more especially in the frame of the ship, it becomes a matter of serious consideration to determine whether it would not be more advantageous to break the vessel up, using the serviceable portions (which will generally be found to be the beams and the lower timbers of the frame) in the construction of another vessel. Should it, however, be deemed advisable to continue the repairs, the most effective and economical proceeding would be to take off the *topsides* outside as low down as the *wales*, and remove the interior planking up to the same line. This method enables the shipwright to have a full inspection of three sides of each timber—allows the defective timbers to be easily removed, and the new ones to be replaced with facility; while the planking that is retained outside and inside serves as an effectual ribband to preserve the form of the ship. The ends of the beams of the several decks should be examined by boring them with an auger from the side, in a slanting direction, into the beam-end; but if the outside planking requires to be taken off in the wake of the beam-ends, an external survey of them can be made without recourse to the internal one. Care should be taken in large repairs that the form of the ship is preserved by means of harpins, ribbands and shores, where required, similar to those used in building. But great caution should be exercised in undertaking large repairs, the attendant expense being more than would arise from building a new ship, in consequence of the two operations of pulling to pieces and putting together again. The knees to the beams of the several decks should be well examined; and any appearance of working—which would be evidenced by the bolt-heads being drawn down—should be carefully considered, and

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an endeavor made to remedy the defect, as the working of a ship on her fastenings is attended with the twofold evil of rapidly weakening the fabric and the production of rot.

The rudder should be unhung after the woodlock is removed; and the pintles and braces by which it is hung should be carefully examined. The head of the rudder should be well inspected to ascertain if the wooden portion has been strained, and that the iron bands are firmly in place.

CHAPTER XVIII.

ON THE DIMENSIONS OF THE MATERIALS USED IN SHIP-BUILDING—SCHEME OF SCANTLINGS, ETC.

THE strain that is brought on the different parts of a wooden ship it is impossible to calculate, and therefore it is by long practice alone that the materials used in ship-building have got the dimensions now considered proper. Of course a ship intended to carry heavy materials, such as iron ore or salt, liable to make the vessel uneasy at sea, ought to be built stronger than a ship intended, say for the cotton or tea trade. Different qualities of materials also require different dimensions to give the same strength to the ship, but still the strength does not depend alone on the dimensions given to the timbers and other materials. Their proper connections with suitable fastenings affect the strength of the ship almost in a still greater degree, and therefore it requires all the skill of an able and experienced ship-builder to give all the materials proper dimensions in proportion to each other and to the dimensions of the ship. The dimensions of the principal materials used in the building of men-of-war, as put in the following table, are mean dimensions in use in different countries, and may therefore be considered suitable in all ordinary cases where the vessel is built of oak or teak or some other timber of nearly the same strength; but if pine or fir is used, the scantlings ought to be one-eighth to one-sixth heavier.

The same scantlings are applicable to merchant vessels, with this observation, that the main-deck beams of a frigate will answer as lower-deck beams of a merchantman of the same breadth, and the upper-deck beams of a frigate as the upper-deck beams of a merchant ship.

As a general rule, if the ship is very long in proportion to her

breadth, the dimensions of some of the materials ought to be greater than put down in the table, and this about in the following proportion: If the length on load water-line is from 5 to 6½ times the main breadth, divide the length by 5, and take the quotient as the breadth, for determining the scantlings of the keel, false keel, deadwood, stem, forefoot, apron, knight-heads, hawse-pieces, stern-post, siding of the frames, keelson, iron diagonals, thickstuff at the floor-heads and futtock-heads, clamps and shelf for the beams, water-ways, spirketing, catheads, riding-bitts, hawse-holes, all the wales and outside planking. All the other scantlings are taken to the real breadth of the ship.

If the length on load water-line is from 6½ to 8 times the breadth, divide the length by 6, and consider the quotient as breadth for the above-mentioned scantlings. If the length is more than 8 times the breadth, divide by 7; and if it is more than 9½ times the breadth, divide by 8, and take the scantlings as before.

This is applicable for men-of-war as well as for merchant vessels, but for steam vessels, intended only to carry passengers, and for mail steamers the scantlings may be made slighter, particularly the moulding of the frames, which according to circumstances might be diminished to something about three-fourths of what is put down in the table.

All the dimensions are given in inches except where otherwise signified.

SCHEME OF SCANTLINGS.

	MOULDED BREADTH IN FEET.							
	50	45	40	35	30	25	20	15
Keel, sided	18	16¾	15	13½	12	10½	8½	6¾
" moulded not less than	18	16½	15	13½	12	11	10	8½
" below the rabbet not less than	10	9	8	7	6	5¼	4½	3¾
" scarphs, long in feet	6	5¾	5	4½	4	3¾	3¼	3
Lips of scarphs, thick	3¾	3½	3¼	3¼	3	2¾	2½	2¼
Number of bolts in each scarph	8	8	8	7	7	5	4	3
Diameter of bolts in the middle of scarph	1	1	1	1	⅞	¾	¾	¾
" of bolts in the lips of scarph	¾	⅝	⅝	⅝	⅝	⅝	½	½
False keel, thick	5	4¾	4	3¾	3	2½	2¼	2
Stem, sided as keel								
" outside the outer edge of rabbet	10	9¼	8½	8	7½	7	6½	6
Scarphs of forefoot, long, feet	4½	4¼	4	3¾	3½	3¼	3	2¾
Knight-heads, sided	18	16¾	15	13½	12	10½	8¾	7¼
Plank between the stem and knight-head, thick	7	7	6	4¾	4	3½	3	2½
Diameter of bolts through knight-head and stem	1⅜	1¼	1⅛	1	⅞	⅞	¾	⅝
Hawse-pieces, number on a side	5	5	5	5	5	3	3	2
" " sided as knight-heads								
Stern-post, sided as the keel								
False-post, thick	5	4¾	4½	4¼	4	3¾	3½	3¼
Wing-transom, up and down	14	12¾	11½	10¼	9	7¾	6½	5¼
" " moulded in the middle	17	15¾	14¼	13	11½	10	8	6

SCHEME OF SCANTLINGS.—*Continued.*

		Moulded Breadth in Feet.							
		50	45	40	35	30	25	20	15
Frames, floor timbers, sided, at least		13½	12¼	11	9¾	8½	7¼	6	4¾
" first futtock as floor timbers; the other futtocks diminishing upward to		11	10½	9¾	8¾	7¾	6¾	5½	4½
" top-timbers, sided		10½	9¾	8¾	7¾	6¾	6	4¾	4
" moulded at cutting down	from	15	14	13	12	10¾	9¼	7¾	6
	to	17½	16	14½	13	11¼	9¾	8	6¼
" at middle between keel and water-line	from	12½	11	9¾	8½	7½	6¼	5½	4½
	to	14½	12	11½	10¼	8¾	7½	6	5
" at load water-line	from	11½	10¼	9	7¾	6½	5½	4½	3¼
	to	13	11½	10	8½	7¼	6	4¾	3¾
" at main deck	from	10½	9¼	8	7	6	5	4	3
	to	12	10¾	9¼	8	6¾	5½	4¼	3¼
" at the upper deck	from	6½	6	5½	5				
	to	7	6½	6	5½				
" at the sheer strake (frigate)		5½	5	4½	4				
" at the sheer strake (sloop)		.....	.....	5½	5¼	5	4½	3¾	3
" bolts, below water-line, square		1¼	1⅛	1	⅞	¾	⅝	½	½
" bolts, above water-line, square		1	1	⅞	¾	⅝	½	½	⅜
Keelson, sided as keel									
" moulded in the middle		18	16¾	15	13½	12	10½	8½	6¾
" moulded at the ends		13½	12½	11¼	10	9	7¾	6½	5¼
" scarphs long, feet		3½	3¼	3	2¾	2½	2¼	2	1¾
" bolts through the keel, diameter		1½	1⅜	1¼	1⅛	1	⅞	¾	⅝
Iron diagonals or riders, breadth		6	5½	5	4½	4	3¾	3½	3
" " or riders, thickness		1¼	1⅛	⅞	¾	¾	⅝	½	⅜
Limber strakes, thick stuff at floor-heads	thick	6½	6	5¼	4¾	4¼	3½	3	2½
and futtock-heads	do at ends	5	4½	4	3½	3	2¾	2½	2¼
Orlop or lower-deck clamps		7	6½	6	5	4	3½	3	2½
Ceiling or footwaling		4	3¾	3½	3¼	3	2½	2¼	2
Hoooks and crutches, iron, breadth		6	5⅝	5½	5⅜	5¼	4¾	3¾	3¼
" " " thickness in middle		4	3⅞	3¾	3⅝	3½	3	2½	2
" " " thickness at ends		1¼	1⅛	1	1	1	¾	¾	⅝
Number of bolts in each		9	9	9	7	7	7	7	5
Diameter of bolts		1¼	1¼	1¼	1⅛	1	1	⅞	¾
Shelf-pieces, orlop or lower deck, up, down		11½	11	10½	10	9⅜	8¾	8	
" " breadth at upper side		13	12½	12	11	9¾	8	4	
" " breadth at the ends		10	9½	9	8	6¾	6	3	
" " breadth at the lower side		8½	8	7¼	6½	5½	4½	3	
" " bolts through ship's side, diameter		1⅛	1	1	⅞	⅞	¾	⅝	
" " main deck, up and down		11½	11	10½	10	9½	8¾	8	7¼
" " main deck, breadth at upper side		13	12½	12	11½	10½	9¾	9	8
" " main deck, breadth at lower side		10	9½	9	8½	8	7½	7	6
" " main deck, breadth at ends ¾ of breadth at the middle									
" " upper deck, up and down		7	7	7	7				
" " upper deck, breadth at upper side		10	9½	9	8½				
" " upper deck, breadth at lower side		7	6½	6	5½				
" " upper deck, bolts through ship's side, diam.		⅞	¾	¾	¾				
Main-deck clamps, number of strakes		3	3	3	3	3	3	2	2
" " " thickness of		7½	6½	5¾	5	4¼	3½	3	2½
" " " thickness of, at the ends		5½	5	4½	4	3¼	2¾	2½	2
Beams, lower deck, up and down, pine or fir		12	11	10	9	8	6	5	
" lower deck, up and down, oak		10½	9½	8½	6½	5	4	3	
" lower deck, breadth		13	12	11	9	8	6¾	5½	
" main deck, up and down, oak		15	13½	12	10	8½	7	5½	4
" main deck, breadth		15½	14	13	11½	10	8½	7	5
" main deck, scarphs, long, at least, feet		10½	9½	9	8				
" upper deck, up and down		9½	9	8½	8				
" upper deck, breadth		10½	10¼	10	9½				
" upper deck, scarphs, long, at least, feet		7	7	7	6½				
" poop and forecastle, up and down		.....	.....	.....	4	3½	3		
" poop and forecastle, breadth		.....	.....	.....	6¼	6	5½		
" rounding up, main deck		8¾	8	7¼	6½	5⅝	4¾	4	3¼
" rounding up, upper deck		8½	8	7	6¼				
" rounding up, poop and forecastle		.....	.....	.....	8¾	8¼	8		
Water-ways, lower deck, breadth		10	9½	9	8½				
" to be cut down over beams		2½	2¼	2	2				
" main deck, breadth		14½	14	13½	12¾	12	11¼	10½	9¼
" to be cut down over the beams		4	3¾	3½	3¼	3	2¾	2¾	2½
" upper deck, breadth		10½	10½	10½	10½				

SCHEME OF SCANTLINGS.—*Continued.*

	Moulded Breadth in Feet.							
	50	45	40	35	30	25	20	15
Water-ways to be cut down over the beams	2¾	2¾	2½	2½				
" poop and forecastle, breadth	.....	.....	.....	10	10	9½		
" to be cut down over the beams	.....	.....	.....	2	2	1¾		
" bolts, lower deck, diameter	1	1	⅞	⅞				
" bolts, main deck, diameter	1¼	1⅛	1	⅞	¾	⅝	½	⅜
" bolts, upper deck, diameter	¾	¾	¾	¾				
Spirketing, main deck, thick	6	5½	5	4½	4	3¼	2¾	2
" upper deck, thick	3½	3½	3¼	3¼				
Carlings, lower deck, square	8	7¼	6¾	6	5	4¼	3½	
" main deck, up and down	10	9	8	6¾	5½	4¾	3¾	2¾
" main deck, at ship's side, breadth	10	9	8	6¾	5½	4⅛	3¾	2¾
" main deck, midships, breadth	12	10¾	9½	8¼	7	5¾	4½	3½
" main deck, at the hatches, breadth	16	14½	12½	10¾	9	7½	6	5
" main deck, at mast partners, breadth	16½	15¼	13¾	12	10¼	8¾	7	5½
" main deck, mast partners up and down	14	12½	11¼	9¼	7¾	6½	5	3½
" upper deck, up and down	6	5¾	5¼	5				
" upper deck, at ship's side, breadth	6	5¾	5½	5				
" upper deck, at midships, breadth	7	6¾	6½	6¼				
" upper deck, at the hatches, breadth	9½	9	8½	8				
" upper deck, mast partners, breadth	10½	10¼	10	9½				
" upper deck, mast partners, up and down	8½	8¼	8	7½				
Ledges, main deck, breadth	11	10	9	8	7	6	5	4
" main deck, up and down	5¼	5	4¾	4½	4¼	3¾	3	2½
" upper deck, breadth	6½	6	5½	5				
" upper deck, up and down	4	4	3¾	3½				
Riding bitts, number of pairs	2	2	2	1	1	1	1	1
" " thickness, square	20	18	16	14	12	10	8	6
" " bolts through beams, diameter	1¼	1⅛	1	⅞	¾	⅝	½	⅜
Topsail sheet bitts, fore and main, square	12½	11¼	10	8¾	7½	6¼	5	
" " " mizen, square	9½	8¾	8					
Bowsprit partners, opening between them	22	19½	17	15	13	10½	8	5½
" " square	15½	14¼	13	11¾	10½	9¾	8	6¾
" " bolts through main-deck beams, diam.	1¼	1⅛	1	⅞	¾	⅝	½	⅜
" " bolts through bowsprit, diameter	3	2¾	2½	2¼	2	1½	1¼	1
Jeer bitts, fore and main, fore and aft	11½	10¾	10	8¾	7½	6½	5¼	
" " fore and main, athwartships	23	21	19½	17½	15	13	10½	
" " mizen, fore and aft	9	8½	8					
" " mizen, athwartships	18	17	16					
" " cross pieces, up and down	6	5½	5	4½	4	3½	3	2½
" " cross pieces, breadth	8½	8	7½	7	6½	6	5½	5
" " bolts, diameter	¾	¾	⅝	⅝	½	½	½	⅜
Coamings and *head-ledges*, main deck " " height above deck	12	12	12	10½	10½	9	8½	8
" " thickness	5	5	5	4	4	3½	3½	3
" " upper deck " " height above deck	4	4	4	4				
" " thickness	4	4	4	4				
Plank of the deck, lower deck, thick	2½	2½	2¼	2¼	2¼	2	2	
" " main deck, thick	4	4	4	3½	3½	3	3	2½
" " upper deck, thick	3	3	3	3				
" " poop and forecastle, thick	.....	.....	.....	2½	2¼	2		
Stanchions under main-deck beams, athwartships	8	7¼	6¼	5¼	4½	4	4	3½
" under main-deck beams, fore and aft	10½	9¼	8¼	7¼	6	4¾	4	3½
Knees of iron, lower deck, breadth	4½	4	3¾	3¼	2⅞	2⅜	2	
" " thickness at throat	3¾	3½	3⅛	2¾	2⅜	2	1⅝	
" " thickness at ends	1	⅞	⅞	¾	⅝	½	⅜	
" " length on beam, feet	3½	3¼	3	2¾	2½	2	1¾	
" " bolts at throat, diameter	1¼	1⅛	1	⅞	¾	⅝	½	
" " other bolts, diameter	1	⅞	¾	⅝	⅝	½	⅜	
" " main deck, breadth	5½	5	4½	4	3½	3	2½	2
" " main deck, thickness at throat	4⅝	4¼	3¾	3⅜	3	2⅝	2⅛	1⅝
" " main deck, thickness at ends	1⅛	1	1	⅞	¾	⅝	½	⅜
" " main deck, length on beam, feet	4	3¾	3½	3¼	3	2½	2	1¾
" " main deck, bolts at throat, diameter	1⅜	1¼	1⅛	1	⅞	¾	⅝	½
" " main deck, other bolts, diameter	1⅛	1	1	⅞	¾	⅝	½	⅜
" " upper deck, breadth	3½	3½	3⅜	3¼				
" " upper deck, thickness at throat	3	3	2⅞	2¾				
" " upper deck, thickness at ends	¾	¾	⅝	½				
" " upper deck, length on beam, feet	3	3	2¾	2½				
" " upper deck, bolts at throat, diameter	1	1	⅞	⅞				

SCHEME OF SCANTLINGS.—*Continued.*

	Moulded Breadth in Feet.							
	50	45	40	35	30	25	20	15
Knees of iron, upper deck, other bolts, diameter	¾	¾	¾	⅝				
Portsill, upper, main decks, up and down	8	8	7½	7				
" lower, main decks, up and down	4	4	3¾	3½	3¼	3	3	2½
" lower, upper deck, up and down	3	3	3	3				
Gunwale, frigate, thick	3	3	3	3				
" sloop, thick	.....	.....	.....	5¾	5	4¼	3½	2¾
Catheads, square	18	16¼	14½	13	11	9	7¼	5½
" supporter, sided	13½	12¼	11	9¾	8¼	7	5½	4¼
Plank of bottom, oak, thick	5	4½	4	3½	3	2¾	2½	2¼
" " " yellow pine or fir, thick	5½	5	4½	4	3½	3¼	2¾	2½
Main-wales, thick	8¼	7½	6¾	6	5¼	4½	3¾	3
" " at the ends	6¼	6	5½	5	4	3½	3	2½
Sheer strake, thick	5	4¾	4½	4¼				
" " at the ends	4	3¾	3½	3¼				
Channels, fore and main, thick at ship's side	8	7¼	6½	5¾	5	4¼	3½	2¾
" fore and main, thick at outer edge	4½	4¼	3¾	3¼	2¾	2½	2¼	2
" mizen, thick at ship's side	6½	6	5¼	4½	4			
" mizen, thick at outer edge	3¾	3½	3½	3¼	2¾			
" bolts through ship's side, diameter	1¼	1	1	⅞	¾			
Hawse-holes, number of	4	4	4	4	4	2	2	2
" interior diameter	18¾	17	15¼	13½	11½	9¾	8	6
" thickness of iron at *under* side	2	1¾	1½	1½	1¼	1	1	¾
" thickness of iron at upper side	1¼	1	1	1	1	¾	¾	½
" bolts, diameter	1¼	1	1	1	1	¾	¾	½
Rudder, breadth about, feet*	5¼	4⅚	4 5/12	4	3½	3	2½	2
" head, diameter	25½	23½	21	18½	16	13½	11	8½
" head, diameter minimum	23	21	19	16½	14	11½	9	6½
" pintles, diameter	3½	3⅛	2¾	2½	2⅛	1¾	1⅜	1⅛
" pintles, length	16	15	14	12¾	11¼	9¾	8	6
" pintles, number	6	6–5	5	5–4	4	4–3	3	3–2
Tiller of iron, length about, feet	11	10	9	8	7	6	5	3½
" " square at rudder head	5⅛	4⅞	4½	4⅛	3¾	3⅛	2⅞	2⅜
" " breadth at the fore end	3½	3¼	3	2¾	2½	2¼	1⅚	1½
" " up and down	2½	2⅜	2¼	2	1⅞	1⅝	1½	1¼

* Or the rudder may be proportioned to the *length* of the ship 2 feet + 1 for every 100 feet; for instance a ship 200 feet long, a 5-feet rudder.

Diameter of Bolts for Wales and Plank of the Bottom.

Thickness of wales or plank	12–11	10–9–8–7	6	5½–5–4½–4	3½–3	2½–2	1½
Diameter of bolts	1⅛	1	⅞	¾	⅝	½	⅜

When two pieces of timber are to be bolted together, the diameter of the bolts may generally be $\frac{1}{12}$th of the thickness of the timber, and this diameter is to be increased by $\frac{1}{16}$th of an inch for every timber the bolt has to go through more than two.

When the length of the tiller is L, the diameter of the barrel of the steering wheel is 0.152 L, but from this diameter must be taken one diameter of the wheel rope, or a spiral be cut out for the rope. The length of the barrel of the wheel is eleven (11) times the diameter of the rope. It must be possible to turn the rudder from 38 to

TABLE XXX.—*Dimensions of Materials for Sea-going Iron Ships.*

Size in Inches.	Main Breadth of Ship in Feet.							
	50	45	40	35	30	25	20	15
Keel, height	12	$11\frac{1}{2}$	11	$9\frac{1}{2}$	8	7	6	$5\frac{1}{2}$
" thickness	$3\frac{1}{4}$ to $2\frac{1}{4}$	3 to 2	3 to 2	3 to 2	$2\frac{3}{4}$ to $1\frac{3}{4}$	$2\frac{1}{2}$ to $1\frac{1}{2}$	2 to $1\frac{1}{2}$	$1\frac{1}{2}$ to 1
Frames, angle-iron, from	$\frac{11}{16}\times 6\frac{1}{2}\times 4$	$\frac{11}{16}\times 6\times 4$	$\frac{5}{8}\times 5\frac{1}{2}\times 3\frac{1}{2}$	$\frac{9}{16}\times 5\times 3\frac{1}{2}$	$\frac{1}{2}\times 4\frac{1}{2}\times 3$	$\frac{7}{16}\times 3\frac{3}{4}\times 2\frac{3}{4}$	$\frac{3}{8}\times 3\times 2\frac{1}{2}$	$\frac{5}{16}\times 2\frac{1}{2}\times 2\frac{1}{2}$
" " to	$\frac{5}{8}\times 6\times 3\frac{1}{2}$	$\frac{5}{8}\times 5\frac{1}{2}\times 3\frac{1}{4}$	$\frac{9}{16}\times 5\times 3$	$\frac{1}{2}\times 5\times 3$	$\frac{7}{16}\times 4\times 2\frac{3}{4}$	$\frac{3}{8}\times 3\frac{1}{2}\times 2\frac{1}{2}$	$\frac{5}{16}\times 3\times 2\frac{1}{4}$	$\frac{1}{4}\times 2\frac{1}{2}\times 2$
Garboard strake, from	$\frac{17}{16}$	$\frac{17}{16}$	$\frac{16}{16}$	$\frac{14}{16}$	$\frac{12}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{8}{16}$
" " to	$\frac{14}{16}$	$\frac{13}{16}$	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{7}{16}$
Strakes from garboard to upper part of the bilge, or to the water-line and sheer-strakes, from	$\frac{16}{16}$	$\frac{15}{16}$	$\frac{14}{16}$	$\frac{13}{16}$	$\frac{12}{16}$	$\frac{10}{16}$	$\frac{8}{16}$	$\frac{7}{16}$
to	$\frac{12}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{6}{16}$	$\frac{5}{16}$	$\frac{4}{16}$
From water-line to sheer-strakes, from	$\frac{14}{16}$	$\frac{14}{16}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{6}{16}$
to	$\frac{8}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{6}{16}$	$\frac{5}{16}$	$\frac{4}{16}$	$\frac{3}{16}$	$\frac{3}{16}$
Beams, stringer-plates upon beam ends, hooks, crutches, floor-plates and keelsons, from	$\frac{14}{16}$	$\frac{14}{16}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{10}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{6}{16}$
to	$\frac{10}{16}$	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{6}{16}$	$\frac{5}{16}$	$\frac{4}{16}$
Beams, height for main deck	$14\frac{1}{2}$	13	11	$9\frac{1}{2}$	8	7	6	$4\frac{1}{2}$
" " upper deck	$9\frac{1}{2}$	9	$8\frac{1}{2}$	8	...	...	...	...
" " lower deck	12	$10\frac{1}{2}$	9	$7\frac{1}{2}$	6	5	4	...
Bulkheads, thickness of plates	$\frac{9}{16}$	$\frac{8}{16}$	$\frac{8}{16}$	$\frac{7}{16}$	$\frac{6}{16}$	$\frac{5}{16}$	$\frac{4}{16}$	$\frac{3}{16}$
Rudder, diameter at head	$6\frac{3}{4}$	$6\frac{1}{2}$	6	5	$4\frac{1}{2}$	$3\frac{3}{4}$	3	$2\frac{1}{4}$
" " heel	$4\frac{1}{2}$	4	$3\frac{1}{2}$	3	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$	2

Diameter of Rivets.

Thickness of plates, inches	$\frac{5}{16}$ to $\frac{7}{16}$	$\frac{1}{2}$ to $\frac{5}{8}$	$\frac{11}{16}$ to $\frac{13}{16}$	$\frac{7}{8}$ to 1
Diameter of rivets	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1

42 degrees to each side. The diameter of the wheel to be from $\frac{1}{6}$ to $\frac{1}{7}$ the breadth of the ship.

When the thickness of the keel will allow it, the keel may be tapered to both ends, so that it is sided in the fore end at the fore-foot $\frac{11}{12}$, and in the after end at the stern-posts $\frac{5}{6}$ of the siding in the middle. The stern-post at the height of the rudder-port, and the stern at the height of the main-wales, are then sided the same as the keel in the middle; but the top of the stem may be $\frac{1}{6}$ more if the timber will allow it. The stem may be joined to the keel in the same manner as the stern-post, which is as strong as with a gripe or forefoot, and this will be especially profitable in large ships, for which a good forefoot may be difficult to procure.

On iron vessels whose dimensions are those given in TABLE XXX.— The rivets, where the seam is to be water-tight, are not to be nearer to the edges of the plates than a space equal to the diameter of the rivets, and not farther from centre to centre than *four* times their diameter, nor less than *three* times their diameter.

Rivets through the plating and frames, and through the angle-irons on the beams, and generally where water-tightness is not required between the pieces joined together, may be placed so far from each other as *eight* times their diameter from centre to centre.

The overlapping of the plates, where double riveting is used, ought not to be less in breadth than *five* times the diameter of the rivets, and where single riveting is used not less than *three* times the diameter of the rivets.

Distance between the frames 15 to 18 inches, and in river steamers 20 to 24 inches. Generally in such steamers the distance between the frames is greater toward the extremities of the vessel than in the middle; say in the engine-room, 15 to 18 inches, while forward and abaft, 20 to 24 inches.

CHAPTER XIX.

EXAMPLE OF GENERAL DIRECTIONS FOR BUILDING A SIDE-WHEEL MAN-OF-WAR STEAMER OF THE FIRST CLASS, LIKE THE "POWHATAN" OR "SUSQUEHANNA."

KEEL.—To be of *white oak*, sided 1 foot 6 inches, and laid straight, without any curve; to be made of two depths—viz., the *upper* or *internal* keel, and the lower keel, but may be in one depth if the timber will work.

The upper keel in depth, 1 foot 2 inches.

The lower keel in depth, 1 foot.

The *rabbet* to be cut on the upper keel; the lower edge of the rabbet being 4 inches above the lower edge of the upper keel. The number of pieces in the upper keel not to exceed six (6), and in the lower keel not to exceed seven (7).

Scarphs to be in length 10 feet, to be plain without *jogs*, and four (4) *coaks* in two rows let in. Coaks, in width, 3½ inches; in thickness, 2½ inches; in length, 16 inches. The ~~*tips*~~ nibs of scarphs to be fastened with 2 copper bolts ¾ inch in diameter, to be *riveted* (*i. e.*, clinched) on; in length, three times the thickness of the *nib*.

The scarphs to be further fastened with 4 copper bolts in each, in diameter 1 inch; to be driven in the spaces between the floor timbers and riveted. Between the upper and lower keel the *joint* to be *fair*, and two rows of coaks to be let in; coaks 18 inches long, 4 inches wide, 3 inches thick and 30 inches asunder.

The upper and lower keels to be fastened together with copper bolts, about 5 feet asunder, ⅞ inch in diameter. The upper keel to be bolted athwartships, near the lower edge, about 5 feet asunder, and the lower keel in the same manner, about 7½ feet asunder, with copper bolts in diameter ⅞ inch.

False keel, in thickness 2 inches; fastened to the main keel with copper bolts 12 inches in length, ⅝ inch in diameter. Whole depth of keel and false keel, clear of rabbet, 1 foot 6 inches.

Deadwood, forward and aft, of *live oak,* sided 1 foot 6 inches. The *stern-post knee* of *live oak,* to be *fayed* on the keel and to the fore side of the *stern-post.* Over this knee the deadwood is to be built, keeping the shortest pieces below and coaking them to each other and to the keel.

Stern-post knee-bolts of copper, in diameter 1⅜ inches, in number 4; of which 2 will be driven through the lower end of the stern-post, and 2 through the after end of the keel. Care must be taken that these bolts do not interfere with those of the deadwood.

Deadwood.—The 7 main bolts of the after deadwood—that is, the 4 last in the keel, and the 3 first in the lower end of the stern-post—to be in diameter 1¾ inches. The remaining bolts in the post and the four next in the keel to be in diameter 1½ inches.

From which to the after square frame they will be driven 2 feet asunder, in diameter 1¼ inches.

When the deadwood is not more than 7 inches deep, the bolt will be in diameter ¾ inch, gradually increasing in size as the depth becomes greater; but they will not in any case, between the aftermost and foremost square frame, be of greater diameter than 1 inch.

These bolts for drawing the deadwood to the keel will be in length about 2⅓ times the depth of the piece through which they are first driven, but when this is within 4 inches of the lower side of the lower keel, let the bolts go through and be clinched as all others.

The *forward deadwood bolts,* before the forward *square frame,* to be about 20 inches asunder, and in diameter 1¼ inches.

The *deadwood knee* to be *fayed* on and coaked to the deadwood; bolts of copper, about 20 inches asunder, and in diameter 1⅜ inches.

The bolts in the *arm* to go through and clinch; those in the *body* to be in length 2½ times the depth of the piece through which they are driven.

Stern-post, of *live oak,* sided at the rabbet 1 foot 6 inches; moulded at the height of *cross seam,* clear of rabbet, 1 foot 3 inches; moulded at the *heel,* clear of the rabbet, 2 feet 4 inches, to keep its full siding on the aft side down to the cross seam, from which it will taper at the heel, on aft side, to 10½ inches.

The rabbet to be cut near the middle of the *main piece* of stern-post, or in that part most free from defects.

The aft side of the rabbet, at the height of the cross-seam, to be kept 11 inches abaft the front of the post, and at the keel from 12 to 16 inches, as the piece will work best.

The deficiency in the main-post to be made up by a *false* or *after-post,* coaked to the *main-post,* each piece having one or two tenons in the keel, according to the size.

Main transom, sided and moulded, 1 foot 8 inches; cross-seam to be 9 inches below top of transom, fastened to the stern-post with three bolts, in diameter 1¼ inches; the remaining *transoms* to side, 1 foot, fastened with two bolts in each, in diameter 1¼ inches.

Stem, of *live oak,* sided 18 inches; scarphs *hooked* (tabled) about 2 inches, and fastened with bolts, in diameter 1¼ inches; the *nibs* secured with bolts, in diameter ¾ of an inch; the rabbet of the stem, if the size and quality of the timber will admit, is not to be cut close to the aft side, but to be so situated that the aft side of the stem may be at or near the *bearding-line.*

Apron, of *live oak,* sided 1 foot 6 inches; moulded at head, at the after corner on a square from the plank, 9 inches; fastened to the stem with bolts of copper and iron about 2 feet asunder, in diameter 1¼ inches.

Timber and Room.—Floor timbers to side from 12 to 14 inches; *first futtocks* to side from 10 to 12 inches; *second futtocks, third futtocks, fourth futtocks, top timbers* and *stanchions,* for a length amidships of 100 feet, to side 11 inches; for the next 40 feet forward and aft to side 10 inches; for the next 35 feet forward and aft these timbers to side 9 inches.

Moulding of the floor timbers in the throat, 18 inches; moulding size at the floor head 12 inches; moulding of frame at the *portsill* or *planks,* 2 feet above the *upper deck,* 7½ inches. The intermediate sizes to be ascertained by a curved diminishing line, and these are the moulding sizes; the timbers are to *hold* on the *square* when ready for planking inside and outside.

The heels of *cant timbers* to have 2 inches left on the inside, to let that much into the deadwood, with a *jog* of 12 inches from their heels, and to be secured by two copper bolts in each pair, in diameter 1⅛ inches.

Frame-bolts in each scarph, asunder 30 inches; those below the third futtock-head to be $1\frac{1}{8}$ inches; those in the floor timbers to be copper; those above the third futtock-head to be 1 inch in diameter.

Keelson to be of *live-oak plank,* in thickness 7 inches; to be *five* planks in height, the planks composing the keelson to be *butted* together and not scarphed; the lower plank to be coaked to the first futtocks; the whole to be coaked together with two rows of seasoned *live-oak* coaks, 10 inches long, 3 inches square and 15 inches asunder.

Bolts for drawing plank to each other to be copper, $\frac{3}{4}$ inch; two copper $1\frac{1}{4}$-inch bolts to be driven through the keelson and each floor timber.

Bolts through the *stemson* and keelson to be of the same size, and clinched outside before the false keel and *gripe* are put on. After the bolts are driven and the corners of the keelson *chamfered,* there will be a *capping* of 3-inch live-oak plank to fill the width between the chamfers nailed to the top of the keelsons, into which the heels of the berth-deck stanchions may mortise.

Knight-heads and *hawse-pieces,* of *live oak,* sided 14 inches; bolted into the apron and into each other with $1\frac{1}{8}$ *iron* bolts; asunder about 2 feet 6 inches.

The spaces between the frames to a *level line,* fore and aft, as high as halfway between the first and second futtock-heads, amidships, to be *filled in* solid and *caulked;* the upper ends to be cut off level.

Before the *clamps* and *inside plank* are put on, the frames to be secured by *diagonal braces* of iron, in breadth 4 inches, and in thickness $\frac{3}{4}$ inch, over which the plank will be fitted; and in each timber to be a bolt through the plate $1\frac{1}{8}$ inches diameter, to be clinched before the *outside plank* is put on; the upper ends of these plates to be 5 feet asunder, under the upper strake of *gun-deck clamps,* the lower end being under the strakes at the first futtock-heads; the upper bolts to be $1\frac{1}{4}$ inches, and go through the clamp and outside plank; the alternate bolts above the copper fastenings to go through the outside plank; the holes to be drilled and *counter-sunk* amidships; the heads of two braces to come on the same frame, the *heels* reaching forward in the *fore body* and aft in the *after body* at an angle of 45°.

Hawse-holes in clear of leads and pipes 16 inches.

Running plank of bottom, of *white oak,* in thickness 5 inches.

Wales, of *white oak,* in thickness 6 inches; in width about 8 inches, to gradually and fairly *diminish* in thickness till they fall in with the *bottom plank* and strake under the *plank-sheer,* which is in thickness to be 5 inches; the five strakes of wale plank below the plank-sheer, three opposite the gun-deck clamps, three at the third futtock-heads and two at the second futtock-heads, to be $1\frac{1}{4}$ inches thicker, and *jogged* that much over the frames; the plank to be put on with *fair edges,* without *hooks* or *jogs.*

Garboard strakes, in thickness next the keel 10 inches; in width, 12 to 15 inches. To allow for thickness, the timbers will be taken off on a level with the top of the deadwood or upper keel, which will be made up in the thickness of the plank next the *garboard,* falling gradually and fairly in with the bottom plank. These strakes to be fastened edgewise through the keel and each other with 1-inch copper bolts 5 feet apart, and into the timber as the other plank with 1-inch bolts. All the fastenings going through to be of *copper,* to a line 19 feet above the lower edge of the rabbet of the keel; from that line upward, *iron* to be used. The plank to be square, fastened from the keel to the plank-sheer; that is, there will be two *through-bolts* in each strake in each frame (except where a *knee-bolt* will answer the purpose) and two short fastenings. The short fastenings to be in diameter $\frac{3}{4}$ inch; the through fastenings, which are to be clenched below, $\frac{7}{8}$ inch.

In each *butt* there will be one through-bolt and one fastening, except the *hood-ends,* where both will go through if practicable. The length of the short fastenings to be twice and one-third the thickness of the plank through which they are driven, taking care that the bolts shall not go through the timber.

Engine or *bilge keelsons,* to be of *white oak,* sided $17\frac{1}{2}$ inches; made or fastened as the main or centre keelsons.

Inside strakes at first and second futtock-heads in number at each butt, three of *white oak,* in thickness 6 inches, fastened with $\frac{3}{4}$-inch bolts.

Berth-deck clamps, to be of *white oak;* six strakes on each side; thickness, 6 inches. The three upper strakes to jog over the timbers, $1\frac{1}{4}$ inches, the plank being that much thicker (namely $7\frac{1}{4}$ inches), fastened with $\frac{7}{8}$-inch bolts. *Seams* to be fair without hooks or jogs, and to be bolted edgewise about 5 feet asunder, with *iron* $\frac{15}{16}$-inch bolts.

Berth-deck beams, of *yellow pine,* sided 12 inches, moulded 14 inches; to have a *spring** of 6 inches in 45 feet, the ends *not* to be *snaped.*

Berth-deck knees: to the ends of each beam there will be one *lodge* and one *lap* and *hanging knee,* each sided 8 inches, fastened with 1⅛-inch bolts.

Carlings, or fore-and-aft pieces, of *yellow pine,* square, 7 inches, in three ranges; that is, one in the middle of the deck, and the others midway between the middle range and the side of the ship.

Ledges, of *yellow pine,* sided, 5 inches; moulded, 6 inches.

Berth-deck plank, of *yellow pine,* in thickness 3½ inches, in width, about 8½ inches, fastened to the beams with *iron spikes* (plugged); in length 7 inches. *Spikes* to be 6 inches long in the ledges. The beams and ledges of this and other decks to have two (2) spikes in each strake.

Water-ways, of *yellow pine;* deck edge, in thickness, 6½ inches, of which 1 inch will jog over the beams; next the water-ways will be two strakes of *yellow pine,* in thickness, 6½ inches, which will likewise jog over the beams and ledges 1 inch. The inner edge of these strakes to be chamfered to the thickness of the deck plank; these strakes to be bolted through the water-way and side of the ship, with *one* bolt in each frame, in diameter 1 inch. The edge of the water-way will be *chined* in 2 inches, the wood taken off thence in a straight line across to the thickness of the spirketing, which is 6 inches. The *thick strakes* and deck edge of water-way to be fastened with ⅝-inch bolts, 11 inches long.

Spirketing, to be of *white oak,* 6 inches; the spirketing and side edge of water-way to be fastened with ⅞-inch bolts.

Coamings and *head-ledges* to be of *yellow pine;* in width, for the coaming, 14½ inches, in thickness, 6½ inches; *chined* on 1½ inches to show 5 inches; height above the deck, 4 inches; to be fastened with ⅞-inch bolts.

Coamings for scuttles, same height above deck, but sided 1 inch less; bolts ¾ inch.

Abreast the *crank hatchway* the *half beams* will side 10 inches.

Beams moulded at the side of ship the same as whole beams, and continue that size 1 foot; from thence they will taper to the coamings of the hatchway to 7 inches; kneed to coamings with *lodge*

* Or round-up.

knees, sided 5 inches, and to the side with lodge and lap knees, sided 7 inches.

The lower edges of beams, ledges and carlings to be rounded.

Stanchions under the berth-deck beams, to be of *white oak*, square, 9 inches; chamfered 1 inch on each corner to within 9 inches of the head and heel, and let into *caps* under the beam.

Breast-hooks, to be of *live-oak*, and all fayed to the timber, sided 12 inches. The *throat-bolt* and the next on each side, in diameter 1⅜ inches; the remaining bolts, 1¼ inches.

The *hooks* (*i. e.*, crutches) aft to be of the same size and secured in the same manner.

Gun and deck clamps, to be of *white oak*, in thickness 6 inches. The two upper and two lower strakes to be 1¼ inches thicker, and jog that much over the timbers. The whole to have fair edges and be bolted edgewise with 1-inch bolts about 5 feet asunder and clear of the *air-ports;* fastenings to be, in diameter, ⅞ inch.

The *air-ports* to be between the *second* and *third* strake, there being no *air-list;* the clamps will reach the spirketing.

Gun-deck beams, of *yellow pine*, sided 13½ inches; moulded 15 inches; to *spring* 6 inches in 45 feet.

Gun-deck knees: to the ends of each beam there will be one lodge knee, one *dagger knee* and one hanging knee.

Lodge and dagger knees, to be sided 8 inches; hanging knees, 9 inches.

Bodies of hanging knees to reach the lower-deck water-way; *arms* to be 5 feet in length. *Knee-bolts* to be 1¼ inches.

Deck, or stern-hook knees, to be sided 9 inches; bolts 1¼ inches. *Knees* to be *white oak* or *live-oak*.

Stanchions on the *berth deck* to be *white oak*, in diameter 8 inches.

Ledges, of *yellow pine;* one (1) between every two beams, except in the range of the hatches, where they will be 2 feet, average distance, asunder; sided 5½ inches, moulded 7 inches.

Coamings and head-ledges of hatches, in height above the deck 10 inches; to be 1 inch thicker than those on the deck below, and fastened with 1-inch bolts.

Gun-deck plank, of yellow pine, in thickness, when planed, 4½ inches; width not to exceed 8 inches, to be fastened with *iron* spikes and *plugged;* spikes in the beams to be 9 inches long, and in the

ledges 8 inches long. To have two strakes next the water-way 9 inches in width, each; jogged over the beams and ledges $1\frac{1}{2}$ inches, in thickness 6 inches.

Water-ways, of *yellow pine;* side edge 5 inches thick; deck edge 6 inches thick; of which $1\frac{1}{2}$ inches jog on the beam; the deck edge to be chined in 2 inches; the wood taken off thence in a straight line to the thickness of the spirketing, 5 inches.

The thick strakes to be bolted edgewise through the water-ways and side of the ship, with one $1\frac{1}{16}$ bolt in each frame, if practicable.

Side edge of the water-way to be fastened with $\frac{3}{4}$-inch bolts.

Spirketing to be of white oak, 5 inches thick. The midships part, when practicable, to be $1\frac{1}{4}$ inches thicker, and jog that much over the timber, where the thickness will be $6\frac{1}{4}$ inches, and to be fastened with $\frac{1}{4}$-inch bolts, as in the outside plank.

Plank-sheer, of *white oak*, 6 inches thick; every other timber to come through; scarphed edgewise and bolted into the water-ways, through the spirketing and into the outside plank with $\frac{3}{4}$-inch bolts. Height of the top of the plank-sheer above the deck to be 2 feet.

Partners of fore and main masts to be of *live-oak*, 15 inches in breadth, 9 inches thick, and framed to admit wedges of 3 inches. To be kneed, as well as those on the berth deck, with lodge and lap knees, sided 6 inches, fastened with $\frac{7}{8}$-inch bolts. Those of the *mizzen-mast* to be of live-oak, 12 inches in breadth, 8 inches thick; knees to be sided 5 inches, bolts to be $\frac{3}{4}$ inch.

*Guard beams** to be of *yellow pine*, sided 20 inches; moulded 26 inches. To be made in two thicknesses, the pieces coaked together and secured with *screw-bolts*. To be kneed with hanging knees at each end; that is, two inside, sided 8 inches. The lodge knees, as the other beams, all to be fastened with screw-bolts, sided 8 inches.

Cable (i. e., *riding*) *bitt*, to be of *live-oak;* square at the head 18 inches, bolts $1\frac{1}{4}$ inches.

Bowsprit bitts to be of *live-oak*, 14 inches square at the head, $1\frac{1}{8}$-inch bolts.

Catheads of *white* or *live-oak*, sided 15 inches; moulded 17 inches, bolts $1\frac{1}{8}$ inches.

* Or paddle-box beams.

Rudder to be 24 inches in diameter at *head,* 5 feet fore and aft at the *heel;* diameter of bolts, 1¼ inches.

Pintles, in number four; in diameter 4½ inches; width of *straps,** 4½ inches.

Stern-timbers, on each side of the rudder, to be of *live-oak,* and kept asunder to clear the rudder-head, sided 10 inches.

Where the timbers run up in range of the wheel-houses they will mould at the head 4¾ inches.

The *plank,* inside and out, to be of *yellow pine* 3 inches thick, and fastened with spikes 5½ inches long.

Between the *thick strakes* and the *clamps* in the hold there will be *trusses* of timber in a contrary direction to the *iron braces,* about 6 inches square.

All the through-bolts of iron above the water-line will have nuts and screws with washers.

Orlop-deck (*cock-pit*) plank to be of yellow pine 2½ inches thick.

Orlop-deck beams to be sided 12 inches, moulded 9 inches. *Orlop-deck lodge knees* to be sided 6 inches and bolted with ⅞-inch bolts.

Beams over the wheel beams to be sided 16 inches, moulded 8 inches.

Height in the clear under the beam, 7 feet; under the gun-deck beam to top of berth-deck plank, 6 feet 9 inches; to top of berth-deck beams to orlop plank, 5 feet 2 inches.

To have two (2) *water-tight bulkheads*—one at the forward fire-room and the other at the after end of the engine-room.

All the timber to be well seasoned and of the very best quality.

United States Steamer "Susquehanna."†

Hull designed by Mr. John Lenthall, Chief Naval Constructor; engines and boilers designed by Mr. C. W. Copeland, Civil and Mechanical Engineer.

Hull.

Length, C. H. measurement	257 feet.
" at 18½ feet draft of water	250 "

* Or braces.

† This vessel was constructed of the very best seasoned timber, and was considered a thoroughly staunch and well-built ship in every respect. For this reason the foregoing directions have been selected as affording a good practical illustration in ship-building.

Extreme breadth	45 feet.
" " over guards	69 "
Depth of hold	26½ "
" keel	1½ "
Displacement of hull at 15½ feet draft	2745 tons.
" " 17½ "	3277 "
" " 19½ "	3824 "

The vessel was barque-rigged and had a *plain* sail area of 21,230 square feet.

Engines.

Made by Murray & Hazlehurst, of Baltimore, Md.; were two inclined, direct-acting, condensing engines, with inclined air-pumps.

Diameter of cylinders	70 inches.
Stroke of piston	10 feet.
Space displacement of both pistons, per stroke	534.51 cubic feet.
Space occupied by engines, fore and aft	49 feet.

Boilers (originally).

There were four *copper* boilers, with double-return ascending flues.

Length of each boiler	15¾ feet.
Breadth " "	15 "
Height " "	12¾ "
Fire surface in all four boilers	8652 sq. feet.
Grate " " "	342 "
Height of chimney above grates	65 feet.
Weight of boilers and appurtenances	184 tons.

Paddle-wheels (radial, common kind).

Diameter from outside to outside	31⅙ feet.
Length of paddles	9½ "
Width " (double)	34 inches.
Area of two paddles	54 sq. feet.
Number of paddles in each wheel	26.
Immersion of lower edge of paddle at 18½ feet draft	64 inches.

Weight and Cost (1847). (*Launched in* 1850.)

	Weight in tons.	Cost.
Hull and equipments	2170	$380,989
Engines, etc., except coal	726	324,681
Armament, etc.	97	4,738
Coal in bunkers	900	
Total	3893	$710,408

VOCABULARY.

VOCABULARY.

An Explanation of the Terms, and of some Elementary Principles, Requisite to be Understood in the Theory and Practice of Naval Construction.

Afloat.—Borne up by, or floating in, the water.

After-Body.—That part of a ship's body abaft the midships or dead-flat. This term is more particularly used in expressing the *figure* or *shape* of that part of the ship.

After Timbers.—All those timbers abaft the MIDSHIPS or DEAD-FLAT.

Air Funnel.—A cavity framed between the sides of some timbers, to admit fresh air into the ship and convey the foul air out of it.

Amidships.—In midships, or in the middle of the ship, either with regard to her length or breadth. Hence that timber or frame which has the greatest breadth and capacity in the ship is denominated the *midship bend.*

Anchor-Lining.—Short pieces of plank, board, or plate iron fastened to the sides of the ship to prevent the bill of the anchor from wounding the ship's side when fishing the anchor.

Anchor Chock.—A chock bolted upon the gunwale abaft the fore-drifts, for the bill of the sheet-anchor to rest on.

To Anchor Stock.—To work planks in a manner resembling the stocks of anchors, by fashioning them in a tapering form from the middle, and working or fixing them over each other, so that the broad or middle part of one plank shall be immediately above or below the butts or ends of two others. This method, as it occasions a great consumption of wood, is only used where particular strength is required, as in the SPIRKETINGS under ports, etc.

An-End.—The position of any mast, etc., when erected perpendicularly on the deck. The top-masts are said to be AN-END when they are hoisted up to their usual stations. This is also a common phrase for expressing the driving of anything in the direction of its length, as to force one plank, etc., to meet the butt of another.

Angle of Incidence.—The angle made with the line of direction by an impinging body at the point of impact; as that formed by the direction of the wind upon the sails or of the water upon the rudder of a ship.

Apron.—A kind of false or inner stem, fayed on the aftside of the stem, from the head down to the deadwood, in order to strengthen it. It is immediately above the foremost end of the keel, and conforms exactly to the shape of the stem, so that the convexity of one applied to the concavity of the other forms one solid piece, which adds strength to the stem and more firmly connects it with the keel.

Arch of the Cove.—An elliptical moulding sprung over the cove at the lower part of the taffrail.

Ash.—Timber much used in ship-building, principally for ladders, gratings, capstan bars, handspikes and oars.

Back of the Post.—The after-face of the STERN-POST.

Backstay Stool.—A short piece of broad plank, bolted edgeways to the ship's side, in the range of the channels, to project and for the security of the dead-eyes and chains for the backstays. Sometimes the channels are left long enough to answer the purpose.

Back-Sweep.—*See* FRAMES.

Balance Frames.—Those *frames* or bends of timber of the same capacity or area which are equally distant from the centre of gravity. *See* FRAMES.

Ballast.—A quantity of iron, stone or gravel, or such other like materials, deposited in a ship's hold when she has no cargo, or too little to bring her sufficiently low in the water. It is used to counterbalance the effort of the wind upon the sails, and give the ship a proper stability, that she may be enabled to carry sail without danger of oversetting.

Barque.—A name given to ships having three masts, without a mizzen top-sail.

Barrel.—The main piece of a capstan or steering-wheel.

Battens.—In general, light scantlings of wood. In ship-building, long narrow laths of ash or fir, their ends corresponding and fitted into each other with mortice and tenon, used in setting fair the sheer-lines on a ship. They are painted black, in order to be the more conspicuous. Battens used on the mould-loft floor are narrow laths, of which some are accurately graduated and marked with feet, inches and quarters, for setting off distances. Battens for gratings are narrow, thin laths of oak.

Beams.—The substantial pieces of timber which stretch across the ship from side to side, to support the decks and keep the ship together by means of the *knees*, etc., their ends being lodged on the shelf or clamps, keeping the ship to her breadth.

Beam Arm, or Fork Beam is a curved piece of timber, nearly of the depth of the beam, scarphed, tabled and bolted, for additional security to the sides of beams athwart large openings in the decks, as the main hatchway and the mast-rooms.

Breast Beams are those beams at the fore part of the quarter-deck and poop and after part of the forecastle. They are sided larger than the rest, as they have an ornamental rail in the front, formed from the solid, and a rabbet one inch broader than its depth, which must be sufficient to bury the plank of the deck, and one inch above for a spurn-water. To prevent splitting the beam in the rabbet, the nails of the deck should be crossed, or so placed, alternately, as to form a sort of zigzag line.

Half Beams are short beams introduced to support the deck where there is no framing, as in those places where the beams are kept asunder by hatchways,

ladder-ways, etc. They are let down on the shelf or clamps at the side, and near midships into fore and aft carlings. On some decks they are abaft the mizen-mast, generally of yellow pine or fir, let into the side tier of carlings.

The Midship Beam is the longest beam of the ship, lodged in the midship frame, or between the widest frame of timbers.

Bearding.—The diminishing of the edge or surface of a piece of timber, etc., from a given line, as on the deadwood, clamps, plank-sheers, fife-rails, etc.

Bearding-Line.—A curved line occasioned by bearding the deadwood to the form of the body; the former being sided sufficiently, this line is carried high enough to prevent the heels of timbers from running to a sharp edge, and forms a rabbet for the timbers to step on; hence it is often called the STEPPING-LINE.

Bed.—A solid framing of timber, to receive and to support the mortar in a bomb vessel.

Beech.—Timber used mainly for chocks, etc.

Beetle.—A large mallet used by caulkers for driving in their reeming-irons to open the seams in order for caulking.

Belly.—The inside or hollow part of compass or curved timber, the outside of which is called the BACK.

Bell-Top.—A term applied to the top of a quarter-gallery when the upper stool is hollowed away, or made like a rim, to give more height; as in the quarter-galleries of small vessels, when the stool of the upper finishing comes home to the side, to complete it overhead.

Bend-Mould, in whole moulding. A mould made to form the futtocks in the square body, assisted by the rising-square and floor-hollow.

Bends.—The frames or ribs that form the ship's body from the keel to the top of the side at any particular station. They are first put together on the ground. That at the broadest part of the ship is denominated the MIDSHIP-BEND or DEAD-FLAT. The forepart of the wales are commonly called *bends.*

Between-Decks.—The space contained between any two decks of a ship.

Bevel.—A well-known instrument, composed of a stock and a movable tongue, for taking of angles on wood, etc., by shipwrights called BEVELINGS.

Beveling Board.—A piece of white pine board, on which the bevelings or angles of the timbers, etc., are described.

Bevelings.—The windings or angles of the timbers, etc. A term applied to any deviation from a square or right angle. Of bevelings there are two sorts, denominated *Standing Bevelings* and *Under Bevelings.* By the former is meant an obtuse angle, or that which is *without a square;* and by the latter is understood an acute angle, or that which is *within a square.*

Bilge.—That part of a ship's floor on either side of the keel which has more of a horizontal than of a perpendicular direction, and on which the ship would rest if on the ground; or, more particularly, those projecting parts of the bottom which are opposite to the heads of the floor timbers amidships, on each side of the keel.

Bilge Trees, or Bilge Pieces, or Bilge Keels.—The pieces of timber fastened under the bilge of boats or other vessels, to keep them upright when on shore, or to prevent their falling to leeward when sailing.

Bilgeways.—A square bed of timber placed under the bilge of the ship, to support her while launching.

Bill-Board.—Projections of timber bolted to the side of the ship and covered with iron, for the bills of the bower anchors to rest on.

Bill-Plate.—The lining of the bill-board.

Bindings.—The iron links which surround the *Dead-Eyes.*

Binding Strakes.—Two strakes of oak plank, worked all the way fore and aft upon the beams of each deck, within one strake of the coamings of the main hatchway, in order to strengthen the deck, as that strake and the midship strakes are cut off by the pumps, etc.

Bins.—Large chests or erections in store-rooms, in which the stores are deposited. They are generally three or four feet deep, and nearly of the same breadth.

Bitts.—Square timbers, fixed to the beams vertically, and enclosed by the flat of the deck. *Topsail Sheet Bitts* are for belaying the topsail sheets to. *Riding Bitts,* for the cables, are covered with an iron casing.

Bitt-Pins.—Iron or wooden pins, passing through the bitt-heads.

To Birth-Up.—A term generally used for working up a topside or bulk-head with board or thin plank.

Black-Strake.—A broad strake, which is parallel to and worked upon the upper edge of the wales, in order to strengthen the ship. It derives its name from being payed with pitch, and is the boundary for the painting of the topsides. Ships having no ports near the wales have generally two black-strakes.

Blocks for building the Ship upon, are those solid pieces of oak timber fixed under the ship's keel upon the ground-ways.

Board.—Timber sawed to a less thickness than plank; all broad stuff of or under one inch and a half in thickness.

Bodies.—The figure of a ship, abstractedly considered, is supposed to be divided into different parts or figures, to each of which is given the appellation of *Body.* Hence we have the terms Fore Body, After Body, Cant Bodies and Square Body. Thus the *Fore Body* is the figure, or imaginary figure, of that part of the ship afore the midships or dead-flat, as seen from ahead. The *After Body,* in like manner, is the figure of that part of the ship abaft the midships or dead-flat, as seen from astern. The *Cant Bodies* are distinguished into *Fore* and *After,* and signify the figure of that part of a ship's body or timbers as seen from either side, which form the shape forward and aft, and whose planes make obtuse angles with the midship line of the ship; those in the Fore Cant Body being inclined to the stem, as those in the After one are to the stern-post. The *Square Body* comprehends all the timbers whose areas or planes are perpendicular to the keel and square with the middle line of the ship, which is all that portion of a ship between the Cant Bodies.

Body-plan.—One of the drawings of the ship, showing the sections made by a series of vertical planes perpendicular to the length of the ship.

Bolsters.—Pieces of oak timber fayed to the curvature of the bow under the hawse-holes, and down upon the upper or lower cheek, to prevent the chain cable from rubbing against the cheek.

*****Bolsters for the Anchor Lining*** are solid pieces of oak, bolted to the ship's side at the fore part of the fore chains, on which the stanchions are fixed that receive the anchor lining. The fore end of the bolster should extend two

* Obsolete.

feet or more before the lining, for the convenience of the man who stands there to assist in fishing the anchor.

Bolsters for Sheets, Tacks, etc., are small pieces of ash or oak fayed under the gunwale, etc., with the outer surface rounded to prevent the sheets and other rigging from chafing.

Bolts.—Cylindrical or square pins of iron or copper, of various forms, for fastening and securing the different parts of the ship, the guns, etc. The figure of those for fastening the timbers, planks, hooks, knees, crutches and other articles of a similar nature is cylindrical, and their sizes are adapted to the respective objects which they are intended to secure. They have round or saucer heads, according to the purposes for which they may be intended; and the points are fore-locked or clinched on rings to prevent their drawing. Those for bolting the frames or beams together are generally square. Of bolts there are a variety of different kinds, as *Eye-bolts*, *Hook-bolts*, *Ring-bolts*, Fixed-bolts, Starting or Drift-bolts, Wrain-bolts, Rag-bolts, Clevis-bolts, Toggle-bolts, etc.

Bottom.—All that part of a ship or vessel that is below the wales. Hence we use the epithet *sharp-bottomed* for vessels intended for quick sailing, and *full-bottomed* for such as are designed to carry large cargoes.

Bow.—The circular part of the ship forward, terminating at the rabbet of the stem.

Bows are of different kinds, as the full or bluff bow, bell bow, straight bow, flare-out or clipper bow, wave bow, water-borne bow, tumble-home bow, and the parabolic bow.

Braces.—Straps of iron, copper or mixed metal, secured with bolts and screws in the stern-post and bottom planks. In their after ends are holes to receive the pintles by which the rudder is hung.

Breadth.—A term more particularly applied to some essential dimensions of the extent of a ship or vessel athwartships, as the BREADTH-EXTREME and the BREADTH-MOULDED, which are two of the principal dimensions given in the building of the ship. The *Extreme-Breadth* is the extent of the midships or dead-flat, with the thickness of the bottom plank included. The *Breadth-Moulded* is the same extent, without the thickness of the plank.

Breadth-Line.—A curved line of the ship lengthwise, intersecting the timbers at their respective broadest parts.

Break.—The sudden termination or rise in the decks of some merchant ships, where the aft and sometimes the fore part of the deck is kept up to give more height between decks, as likewise at the drifts.

Breast-Hooks.—Large pieces of compass timber fixed within and athwart the bows of the ship, of which they are the principal security, and through which they are well bolted. There is generally one between each deck, and three or four below the lower deck, fayed upon the plank. Those below are placed square to the shape of the ship at their respective places. The Breast-Hooks that receive the ends of the deck planks are also called DECK-HOOKS, and are fayed close home to the timbers in the direction of the decks.

Brig.—A vessel with two masts, and fully square-rigged.

Brigantine.—The same as a brig, but without a square mainsail.

Brig (Hermaphrodite).—A vessel with two masts, fully square-rigged on the foremast only.

Broken-Backed or Hogged.—The condition of a ship when the sheer has departed from the regular and pleasing curve with which it was originally built. This is often occasioned by the improper situation of the centre of gravity, when so posited as not to counterbalance the effort of the water in sustaining the ship, or by a great strain, or from the weakness of construction. The latter is the most common circumstance, particularly in some clipper ships, owing partly to their great length, sharpness of floor, or general want of strength in the junction of the component parts.

Bucklers.—Lids or shutters for closing the hawse-holes, and thus keeping the sea out. There are generally grooves in them, to fit over the chain cables.

Bum-Kin, or more properly Boom-Kin.—A projecting piece of oak or spruce pine on each bow of a ship, fayed down upon the false rail or rail of the head, with its heel cleated against the knighthead in large, and the bow in small ships. It is secured outward by an iron rod or rope lashing, which confines it downward to the knee or bow, and is used for the purpose of hauling down the tack of the foresail.

Burthen.—The weight or measure that any ship will carry or contain when fit for sea.

Butt.—The joints of the planks endwise; also the opening between the ends of the planks when worked for caulking. Where caulking is not used, the butts are rabbetted, and must fay close.

Buttock.—That rounding part of the body abaft, bounded by the fashion-pieces, and at the upper part by the wing transom.

Buttock-Lines.—(On the Sheer Draught.) Curves lengthwise, representing the ship as cut in vertical sections. On the half-breadth and body-plans they are projected as straight lines.

Caisson.—A sort of floating tank or dam, having generally both ends similar in form to the bow of a vessel. It is used for closing the entrance to a dry-dock, and is usually fitted with steam pumps and machinery, by means of which it may be sunk or raised, as required. The bow and stern of the caisson fit a groove at the dock entrance. The orifice in the bottom of the caisson, by means of which the water is admitted and the machine sunk, is called a *penstock.*

Camber.—Hollow or arching upward. The decks are said to be *cambered* when their height increases toward the middle, from stem to stern, in the direction of the ship's length.

Camel.—A machine for lifting ships over a bank or shoal, originally invented by the celebrated De Witt, for the purpose of conveying large vessels from Amsterdam over the Pampus. They were introduced into Russia by Peter the Great, who obtained the model when he worked in Holland as a common shipwright, and were used at St. Petersburg for lifting ships of war built there over the bar of the harbor. A camel is composed of two separate parts, whose outsides are perpendicular and insides concave, shaped so as to embrace the hull of a ship on both sides. Each part has a small cabin, with sixteen pumps and ten plugs, and contains twenty men. They are braced to the underpart of the ship by means of cables, and entirely enclose its sides and bottom. Being then towed to the bar, the plugs are opened, and the water admitted until the camel sinks with the ship and runs aground. Then, the water being pumped out, the camel rises, lifts up the vessel, and the whole is

towed over the bar. This machine can raise the ship eleven feet, or, in other words, make it draw eleven feet less water.

Cant.—A term signifying the inclination that anything has from a square or perpendicular. Hence the shipwrights say,

Cant-Ribbands are those ribbands that do not lie in a horizontal or level direction, or square from the middle line, but nearly square from the timbers, as the diagonal ribbands. *See* RIBBANDS.

Cant-Timbers are those timbers afore and abaft, whose planes are not square with, or perpendicular to, the middle line of the ship.

Caps.—Square pieces of oak laid upon the upper blocks on which the ship is built, to receive the keel. They should be of the most freely-grained oak, that they may be easily split out when the false keel is to be placed beneath. The depth of them may be a few inches more than the thickness of the false keel, that it may be set up close to the main keel by slices, etc.

Capstan.—A mechanical contrivance for raising the anchor.

A Cap Scuttle.—A framing composed of coamings and head-ledges, raised above the deck, with a flat or top which shuts closely over into a rabbet.

Carling.—Timber cut to a rectangular form, and above 4½ inches the smallest way.

Carlings.—Long pieces of timber, above four inches square, which lie fore and aft, in tiers, from beam to beam, into which their ends are scored. They receive the ends of the ledges for framing the decks. The carlings by the side of, and for the support of, the mast, which receive the framing round the mast called the partners, are much larger than the rest, and are named the MAST CARLINGS. Besides these there are others, as the PUMP CARLINGS, which go next without the mast carlings, and between which the pumps pass into the well; and also the fire-hearth carlings, that let up under the beam on which the galley stands, with stanchions underneath, and chocks upon it, fayed up to the ledges for support.

Carvel Work.—A term applied to cutters and boats, signifying that the seams of the bottom-planking are square, and made tight by caulking, as those of ships. It is opposed to the phrase CLINCHER-BUILT, which see.

Cathead.—A piece of timber with sheaves in the end, projecting from the bow of a ship, for the purpose of raising the anchor after the cable has brought it clear of the water. In large ships, the cathead laps under a forecastle beam, the inner part being called the *cat-tail*. It is strengthened outside from underneath by a knee, called a *supporter*. The cathead is iron-bound, and is braced with iron knees forward and aft.

Caulking.—Forcing oakum into the seams and between the butts of the plank, etc., with iron instruments, in order to prevent the water penetrating into the ship.

Ceiling or Footwaling.—The inside planks of the bottom of the ship.

Centre of Buoyancy, or Centre of Gravity of Displacement. The centre of that part of the ship's body which is immersed in the water, and which is also the centre of the vertical force that the water exerts to support the vessel.

Centre of Effort of Sail.—That point in the plane of the sails at which the whole transverse force of the wind is supposed to be collected.

Centre of Gravity.—That point about which all the parts of a body do, in

any situation, exactly balance each other. Hence, 1. If a body be suspended by this point as the centre of motion, it will remain at rest in any position indifferently. 2. If a body be suspended in any other point, it can rest only in two positions, viz: when the centre of gravity is exactly above or below the point of suspension. 3. When the centre of gravity is supported, the whole body is kept from falling. 4. Because this point has a constant tendency to descend to the centre of the earth; therefore, 5. When the point is at liberty to descend, the whole body must also descend, either by sliding, rolling or tumbling over.

Centre of Lateral Resistance.—The centre of resistance of the water against the side of a vessel in a direction perpendicular to her length.

Centre of Motion.—That point of a body which remains at rest whilst all the other parts are in motion about it; and this is the same in bodies of one uniform density throughout, as the centre of gravity.

Centre of Oscillation.—That point in the axis or line of suspension of a vibrating body, or system of bodies, in which, if the whole matter or weight be collected, the vibrations will still be performed in the same time, and with the same angular velocity, as before.

Centre of Percussion, in a moving body, is that point where the percussion or stroke is the greatest, and in which the whole percutient force of the body is supposed to be collected. PERCUSSION is the impression a body makes in falling or striking upon another, or the shock of bodies in motion striking against each other. It is either direct or oblique; *direct* when the impulse is given in a line perpendicular to the point of contact, and *oblique* when it is given in a line oblique to the point of contact.

Centre of Resistance to a Fluid.—That point in a plane to which, if a contrary force be applied, it shall just sustain the resistance.

Chain or Chains.—The links of iron which are connected to the binding that surrounds the dead-eyes of the channels. They are secured to the ship's side by a bolt through the toe-link, called a *chain-bolt.*

Chain-Bolt.—A large bolt to secure the chains of the dead-eyes, for the purpose of securing the masts by the shrouds.

Chain-Plates.—Thick iron plates, sometimes used, which are bolted to the ship's sides, instead of chains to the dead-eyes, as above.

Chamfering.—Taking off the sharp edge from timber or plank, or cutting the edge or end of anything bevel or aslope.

Channels.—The broad projection or assemblage of planks fayed and bolted to the ship's sides, for the purpose of spreading the shrouds with a greater angle to the dead-eyes. They should therefore be placed either above or below the upper deck ports, as may be most convenient. But it is to be observed, that if placed too high, they strain the sides too much, and if placed too low, the shrouds cannot be made to clear the ports without difficulty. Their disposition will therefore depend upon that particular which will produce the greatest advantage. They should fay to the sides only where the bolts come through, having an open space of about two inches in the rest of their length, to admit a free current of air, and a passage for wet and dirt, in order to prevent the sides from rotting.

Channel Wales.—Three or four thick strakes worked between the upper and lower deck ports in two-decked ships, and between the upper and middle deck

ports in three-decked ships, for the purpose of strengthening the topside. They should be placed in the best manner for receiving the chain and preventer bolts, the fastenings of the deck-knees, etc.

Cheeks.—Knees of oak timber, which support the knee of the head, and which they also ornament by their shape and mouldings. They form the basis of the head, and connect the whole to the bows, through which and the knee they are bolted.

****Chestrees.***—Pieces of oak timber, fayed and bolted to the topsides, one on each side, abaft the fore-channels, with a sheave fitted in the upper part for the convenience of hauling home the main tack.

Chine.—That part of the waterways which is left the thickest, and above the deck-plank. It is bearded back, that the lower seam of the spirketing may be more conveniently caulked, and is gouged hollow in front, to form a water-course.

To Chinse.—To caulk slightly, with a knife or chisel, those seams or openings that will not bear the force required for caulking in a more thorough manner.

Clamps.—Those substantial strakes worked within the ship, and upon which the ends of the beams are placed when there is no shelf.

Clean.—A term generally used to express the acuteness or sharpness of a ship's body; as when a ship is formed very acute or sharp forward, and the same aft, she is said to be *clean* both forward and aft.

†***Clincher-Built.***—A term applied to the construction of some vessels and boats, when the planks of the bottom are so disposed that the lower edge of every plank overlays the next under it, and the fastenings go through and clinch or turn upon the timbers. It is opposed to the term CARVEL-WORK.

Clinching or Clenching.—Spreading the point of a bolt upon a ring, etc., by beating it with a hammer, in order to prevent its drawing. (Same as Riveting.)

Coaking or Coaging.—Sometimes called doweling. The placing of pieces of hard wood, either circular or square, in the edges or surfaces of any pieces that are to be united together, to prevent their working or sliding over each other.

Coamings.—The raised borders of oak about the edge of the hatches and scuttles, which prevent water from flowing down from off the deck. Their inside upper edge has a rabbet to receive the gratings.

Cock-Pit or Orlop.—Half decks forward and aft, below the berth-deck.

Companion.—In ships of war, the framing and sash-lights upon the quarter-deck or poop, through which the light passes to the commander's apartments. In merchant ships it is the birthing or hood round the ladder-way, leading to the master's cabin, and in small ships is chiefly for the purpose of keeping the sea from beating down.

Compass Timber.—Any timber curved in shape.

Compressor.—An iron lever (bent), having one end secured to the beam nearest the chain pipes in the deck by a bolt, round which it is made to turn. Its use is to check the cable when running out.

Conversion.—The art of cutting and moulding timber, plank, etc., with the least possible waste.

Coping.—Turning the ends of iron lodging-knees so as they may hook into the beams.

* Obsolete. † Or clinker-built.

Corvette.—A flush-decked vessel, ship-rigged, with a uniform battery fore and aft.

Counter.—A part of the stern—the *Lower Counter* being that arched part of the stern immediately above the wing-transom. Above the lower counter is the *Second Counter*, the upper part of which is the under part of the lights or windows. The counters are parted by their rails, as the lower counter springs from the tuck-rail, and is terminated on the upper part by the lower counter-rail. From the upper part of the latter springs the upper or second counter, its upper part terminating in the upper counter-rail, which is immediately under the lights.

Counter-sunk.—The hollows in iron plates, etc., which are excavated by an instrument called a counter-sunk bitt, to receive the heads of screws or nails, so that they may be flush or even with the surface.

Counter Timbers.—The right-aft timbers which form the stern. The longest run up and form the lights, while the shorter only run up to the under part of them, and help to strengthen the counter. The side counter timbers are mostly formed of two pieces, scarphed together in consequence of their peculiar shape, as they not only form the right-aft figure of the stern, but partake of the shape of the topside also.

Cove.—The arch-moulding sunk in at the foot or lower part of the taffrail.

Crab.—A sort of little capstan, formed of a kind of wooden pillar, whose lower end works in a socket, whilst the middle traverses or turns round in partners, which clip it in a circle. In its upper end are two holes to receive bars, which act as levers, and by which it is turned round, and serves as a capstan for raising weights, etc. By a machine of this kind, so simple in its construction, may be hove up the frame timbers, etc., of vessels when building. For this purpose it is placed between two floor timbers, while the partners which clip it in the middle may be of four or five-inch plank, fastened on the same floors. A block is fastened beneath in the slip, with a central hole for its lower end to work in. Besides the crab here described, there is another sort, which is shorter and portable. The latter is fitted in a frame composed of cheeks, across which are the partners, and at the bottom a little platform to receive the spindle.

Cradle.—A strong frame of timber, etc., placed under the bottom of a ship in order to conduct her steadily in her ways till she is safely launched into water sufficient to float her.

Cradle Bolts.—Large ring-bolts in the ship's side, on a line with and between the toe-links of the chain plates.

Crank.—A term applied to ships built too deep in proportion to their breadth, and from which they are in danger of oversetting.

Croaky.—A term applied to plank when it curves or compasses much in short lengths.

Cross Spalls.—Deals or fir plank nailed in a temporary manner to the frames of the ship at a certain height, and by which the frames are kept to their proper breadths until the deck-knees are fastened. The main and top timber breadths are the heights mostly taken for spalling the frames, but the height of the ports is much better; yet this may be thought too high if the ship is long in building.

Crutches or Clutches.—The crooked timbers fayed and bolted upon the

footwaling abaft, for the security of the heels of the half-timbers. Also, stanchions of iron or wood, whose upper parts are forked to receive rails, spare masts, yards, etc.

Cup.—A solid piece of cast iron let into the step of the capstan, and in which the iron spindle at the heel of the capstan works.

Cuppy.—A defect in timber, where a portion of the heart has separated from the outside. Frosts or lightning may cause the annular fibres thus to separate.

Cutter.—Properly, a small, sloop-rigged vessel. Certain boats of a man-of-war are also termed cutters, as the first, second, third and fourth cutters of a frigate.

Cutting-Down Line.—The elliptical curve line forming the upper side of the floor timbers at the middle line. Also the line that forms the upper part of the knee of the head, above the cheeks. The cutting-down line is represented as limiting the depth of every floor timber at the middle line, and also the height of the upper part of the deadwood afore and abaft.

Dagger.—A piece of timber that faces on to the poppets of the bilgeways, and crosses them diagonally, to keep them together. The plank that secures the heads of the poppets is called the *dagger plank.* The word *dagger* seems to apply to anything that stands diagonally or aslant.

Dagger-Knees.—Knees to supply the place of hanging knees. Their side-arms are brought up aslant, or nearly to the under side of the beams adjoining. They are chiefly used to the lower deck-beams of merchant ships, in order to preserve as much stowage in the hold as possible. Any straight hanging knees, not perpendicular to the side of the beam, are in general termed *dagger-knees.*

Davits.—Pieces of timber or iron projecting over the side of the ship or the stern, for the purpose of raising the waist, quarter or stern boats. *Fish Davits* are booms, goose-necked to the foremast, and used for fishing the anchor.

Dead-Eyes.—Pieces of oak or elm, of a round shape, used for reeving the lanyards of standing rigging.

Dead-Flat.—A name given to that timber or frame which has the greatest breadth and capacity in the ship, and which is generally called the *midship bend.* In those ships where there are several frames or timbers of equal breadth or capacity, that which is in the middle should be always considered as *dead-flat,* and distinguished as such by this character, ⊗. The timbers before the dead-flat are marked A, B, C, etc., in order, and those abaft the dead-flat by the figures 1, 2, 3, etc.

Dead-Rising, or Rising Line of the Floor.—Those parts of the floor or bottom, throughout the ship's length, where the sweep or curve at the head of the floor-timber is terminated or inflects to join the keel. Hence, although the rising of the floor at the midship-flat is but a few inches above the keel at that place, its height forward and aft increases according to the sharpness of form in the body. Therefore the rising of the floor in the *sheer plan* is a curved line drawn at the height of the ends of the floor-timbers, and limited at the main frame, or dead-flat, by the dead-rising—appearing in flat ships nearly parallel to the keel for some timbers afore and abaft the midship frame; for which reason these timbers are called *flats;* but in sharp ships it rises gradually from the main frame, and ends on the stem and post.

Dead-Water.—The eddy water which the ship draws after her at her seat or line of flotation in the water, particularly close aft. To this particular great attention should be paid in the construction of a vessel, especially in those with square tucks, for such, being carried too low in the water, will be attended with great eddies or much *dead-water*. Vessels with a round buttock have but little or no dead-water, because by the rounding or arching of such vessels abaft the water more easily recovers its state of rest.

Deadwood.—That part of the basis of a ship's body, forward and aft, which is formed by solid pieces of timber scarphed together lengthwise on the keel. These should be sufficiently broad to admit of a stepping or rabbet for the heels of the timbers, that the latter may not be continued downward to sharp edges; and they should be sufficiently high to seat the floors. Afore and abaft the floors the deadwood is continued to the cutting-down line, for the purpose of securing the heels of the cant-timbers.

Deal.—Fir, similar to plank.

Depth in the Hold.—The height between the floor and the lower deck. This is one of the principal dimensions given for the construction of a ship. It varies according to the height at which the guns are required to be carried from the water, or according to the trade for which a vessel is designed.

Depth at the Side.—A term used to denote the height of the rail in plan, or roughtree rail above the bottom of the false keel. The entire elevation of the ship on the sheer-plan.

Diagonal Line.—A line cutting the body-plan diagonally from the timbers to the middle line. It is square with, or perpendicular to, the shape of the timbers, or nearly so, till it meets the middle line.

Diagonal Ribband.—A narrow plank, made to a line formed on the half-breadth plan, by taking the intersections of the diagonal line with the timbers in the body-plan to where it cuts the middle line in its direction, and applying it to their respective stations on the half-breadth plan, which forms a curve, to which the ribband is made as far as the cant-body extends, and the square frame adjoining.

Displacement.—The volume of water displaced by the immersed body of the ship, and always exactly equal to the weight of the body. The light displacement is the weight of the hull only, while the load displacement is the weight of the hull and all it contains.

Disposition.—A drawing representing the timbers that compose the frame, so that they may be properly disposed with respect to the ports, etc.

Dog.—An iron implement used by shipwrights, having a fang at one, or sometimes at each end, to be driven into any piece, for supporting it while hewing, etc. Another sort has a fang in one end and an eye in the other, in which a rope may be fastened, and used to haul anything along.

Dog-Shore.—A shore particularly used in launching.

Doubling.—Planking of ships' bottoms twice. It is sometimes done to new ships when the original planking is thought to be too thin; and in repairs it strengthens the ship, without driving out the former fastenings.

Dove-Tail.—To join two pieces together with a score and notch—the score resembling a dove's tail.

Dove-Tail Plate.—Metal plates, formed like dove-tails, for uniting together the keel and stern-post.

Draught.—The drawing or design of the ship upon paper, describing the different parts, and from which the ship is to be built. It is usually drawn by a scale of one-quarter of an inch to a foot, so divided or graduated that the dimensions may be taken to one inch. It is divided into three parts, known as the sheer, body and half-breadth plans.

Draft of Water.—The depth of water a ship displaces when she is afloat.

Drag.—Excess of draft of water aft over that forward, or the reverse.

Driver.—The foremost spur on the bilgeways, the heel of which is fayed to the foreside of the foremost poppet, and cleated on the bilgeways, and the sides of which stand fore and aft. It is now seldom used.

Drumhead.—The head of a capstan, formed of semi-circular pieces of elm, which, framed together, form the circle into which the capstan-bars are fixed.

Druxey.—A state of decay in timber, with white spongy veins—the most deceptive of any defect.

Edging of Plank.—Sawing or hewing it narrower.

Ekeing.—Making good a deficiency in the length of any piece by scarphing or butting, as at the end of deck-hooks, cheeks or knees. The *ekeing* at the lower part of the supporter under the cathead is only to continue the shape and fashion of that part, being of no other service; and if the supporter were stopped short without an ekeing, it would be the better, as it causes the side to rot, and commonly appears fair to the eye in but one direction. The EKEING is also the piece of carved work under the lower part of the quarter-piece at the after part of the quarter-gallery.

Elevation.—The orthographic draught, or perpendicular plan, of a ship, whereon the heights and lengths are expressed. It is called by shipwrights the SHEER-DRAUGHT.

Entrance.—A term applied to the fore part of the ship under the load water-line, as, "She has a fine entrance," etc.

Even Keel.—A ship is said to swim on an even keel when she draws the same quantity of water abaft as forward.

Facing.—Setting one piece, about an inch in thickness, on to another, in order to strengthen it.

Fair.—A term to denote the evenness or regularity of a curve or line.

Falling Home, or, by some, Tumbling Home.—The inclination which the topside has within from a perpendicular.

False Keel.—A second keel, composed of white oak or elm plank, or thick-stuff, fastened in a slight manner under the main keel, to prevent it from being rubbed. Its advantages also are, that if the ship should strike the ground, the false keel will give way, and thus the main keel will be saved; and it will be the means of causing the ship to hold the wind better.

False Post.—A piece tabled on to the after part of the heel of the main part of the stern-post. It is to assist the conversion and preserve the main post, should the ship tail aground.

False Rail.—A rail fayed down upon the upper side of the main or upper rail of the head. It is to strengthen the head-rail, and forms the seat of ease at the after end next the bow.

Fashion Pieces.—The timbers so called from their fashioning the after part of the ship in the plane of projection, by terminating the breadth and forming

the shape of the stern. They are united to the ends of the transoms and to the deadwood.

To Fay.—To join one piece so close to another that there shall be no perceptible space between them.

Fife-Rail.—The rails around the several masts, for the running rigging to belay to.

Filling-Timbers.—The intermediate timbers between the frames that are gotten up into their places singly, after the frames are ribbanded and shored.

Fire-Hearth.—The platform on which the galley stands. The conveniences in the galley for cooking, as the grate, oven and coppers (boilers), were formerly termed the fire-hearth.

Flaring.—The reverse of *Falling* or *Tumbling Home.* As this can be only in the forepart of the ship, it is said that a ship has a *flaring bow* when the topside falls outward from a perpendicular. Its uses are to shorten the cathead and yet keep the anchor clear of the bow. It also prevents the sea from breaking in upon the forecastle.

Flats.—A name given to the timbers amidships that have no bevelings, and are similar to dead-flat, which is distinguished by this character ⊗. *See* DEAD-FLAT.

Floor.—The bottom of a ship, or all that part on each side of the keel which approaches nearer to a horizontal than a perpendicular direction, and whereon the ship rests when aground.

Floors, or Floor Timbers.—The timbers that are fixed athwart the keel, and upon which the whole frame is erected. They generally extend as far forward as the foremast, and as far aft as the after square timber, and sometimes one or two cant-floors are added.

Flush.—With a continued even surface, as A FLUSH DECK, which is a deck upon one continued line, without interruption, from fore to aft.

Fore Body.—That part of the ship's body afore the midships or dead-flat. *See* BODIES. This term is more particularly used in expressing the *figure* or *shape* of that part of the ship.

Fore-Foot.—The foremost piece of the keel.

Forelock.—A thin circular wedge of iron, used to retain a bolt in its place, by being thrust through a mortise hole at the point of the bolt. It is sometimes turned or twisted round the bolt to prevent its drawing.

Fore-Peek.—Close forward under the lower deck.

Frames.—The bends of timber which form the body of the ship, each of which is composed of one *floor-timber*, two or three *futtocks*, and a *top-timber* on each side, which, being united together, form the frame. Of these frames or bends that which encloses the greatest space is called the *midship* or *main frame* or *bend.* The arms of the floor timber form a very obtuse angle, and in the other frames this angle decreases or gradually becomes sharper, fore and aft, with the middle line of the ship. Those floors which form the acute angles afore and abaft are called the *Rising Floors.* A frame of timbers is commonly formed by arches of circles, called *Sweeps*, of which there are generally five. 1st. The *Floor Sweep*, which is limited by a line in the body-plan perpendicular to the plane of elevation, a little above the keel; and the height of this line above the keel is called the *Dead Rising.* The upper part of this arch forms the head of the floor timber. 2d. The *Lower Breadth Sweep*, the centre of which is in the

line representing the lower height of breadth. 3d. The *Reconciling Sweep.* This sweep joins the two former, without intersecting either, and makes a fair curve from the lower height of breadth to the rising line. If a straight line be drawn from the upper edge of the keel to touch the back of the floor sweep, the form of the midship frame below the lower height of breadth will be obtained. 4th. The *Upper Breadth Sweep,* the centre of which is in the line representing the upper height of breadth of the timber. This sweep described upward forms the lower part of the top-timber. 5th. The *Top-Timber Sweep,* or *Back Sweep,* is that which forms the hollow of the top-timber. This hollow is, however, very often formed by a mould, so placed as to touch the upper breadth-sweep, and pass through the point limiting the half-breadth of the top-timber.

Frame Timbers.—The various timbers that compose a frame bend, as the floor timber, the first, second, third and fourth futtocks, and top-timber, which are united by a proper shift to each other, and bolted through each shift. They are often kept open for the advantage of the air, and fillings fayed between them in wake of the bolts. Some ships are composed of frames only, and are supposed to be of equal strength with others of larger scantling.

Futtocks.—The separate pieces of timber of which the frame timbers are composed. They are named according to their situation, that nearest the keel being called the first futtock, the next above the second futtock, etc.

Galliot.—A Dutch craft, with a full bow and lofty, round stern.

Garboard Strake.—That strake of the bottom which is wrought next the keel, and rabbets therein.

Goose-Neck.—An iron hinged bolt, with strap to clasp it, used on the spanker, lower and fish booms. The bolt forelocks below a sort of gudgeon.

Grain-Cut.—Cut across the grain.

Gratings.—Lattice coverings for the hatchways and scuttles.

Gripe.—A piece of white oak or elm timber that completes the lower part of the knee of the head, and makes a finish with the fore-foot. It bolts to the stem, and is farther secured by two plates of copper in the form of a horse-shoe, and therefrom called by that name.

Groundways.—Large pieces of timber, generally defective, which are laid upon piles driven in the ground, across the dock or slip, in order to make a good foundation to lay the blocks on, upon which the ship is to rest.

Gudgeons.—The hinges upon which the rudder turns. Those fastened to the ship are called braces, while those fastened to the rudder are called pintles.

Gunwale.—That horizontal plank which covers the heads of the timbers between the main and fore drifts.

Half-Breadth Plan.—A ship-drawing, showing a series of longitudinal transverse sections.

Half-Timbers.—The short timbers in the cant bodies which are answerable to the lower futtocks in the square body.

Hance.—The sudden breaking-in from one form to another, as when a piece is formed, one part eight-square and the other part cylindrical, the part between the termination of these different forms is called the hance; or the parts of any timber where it suddenly becomes narrower or smaller.

Hanging-Knee.—Those knees against the sides whose arms hang vertically or perpendicular.

Harpins.—Pieces of oak, similar to ribbands, but trimmed and beveled to the

shape of the body of the ship, and holding the fore and after cant bodies together until the ship is planked. But this term is mostly applicable to those at the bow; hence arises the phrase "lean and full harpin," as the ship at this part is more or less acute.

Hawse-Holes.—The apertures forward, lined with iron casings, for the chain cables to pass through.

Hawse-Hook.—The breast hook at the hawse-holes.

Hawse-Pipes or Chain-Pipes.—The apertures in the deck, lined with iron, through which the chain cables lead to the lockers.

Hawse-Lining.—The lining of the hawse-holes and chain-pipes. The lining is composed of a lead casing, covered with an iron casing.

Head.—The upper end of anything, but more particularly applied to all the work fitted afore the stem, as the figure, the knee, rails, etc. A "scroll head" signifies that there is no carved or ornamental figure at the head, but that the termination is formed and finished off by a *volute*, or scroll turning outward. A "fiddle head" signifies a similar kind of finish, but with the scroll turning aft or inward.

Head-Ledges.—The 'thwartship pieces which frame the hatchways and ladderways.

Head-Rails.—Those rails in the head which extend from the back of the figure to the cathead and bows, which are not only ornamental to the frame, but useful to that part of the ship.

Heel.—The lower end of a tree, timber, etc. A ship is also said to *heel* when she is not upright, but inclines under a side pressure.

Hogging.—*See* BROKEN-BACKED. A ship is said to *hog* when the middle part of her keel is so strained as to curve or arch upward. This term is therefore opposed to *sagging*, which, applied in a similar manner, means that the keel, by a different sort of strain, curves downward.

Hold.—That part of the ship below the lower deck, between the bulkheads, which is reserved for the stowage of ballast, water and provisions in ships of war, and for that of the cargo in merchant vessels.

Hooding-Ends.—Those ends of the planks which bury in the rabbets of the stem and stern-post.

Horse-Iron.—An iron fixed in a handle, and used with a beetle by caulkers, to *horse-up* or harden in the oakum.

Horse-Shoes.—Large straps of iron or copper shaped like a horse-shoe and let into the stem and gripe on opposite sides, through which they are bolted together, to secure the gripe to the stem.

Hull.—The whole frame or body of a ship, exclusive of the masts, yards, sails and rigging.

In and Out.—A term sometimes used for the scantling of the timbers, the moulding way, but more particularly applied to those bolts in the knees, riders, etc., which are driven through the ship's sides, or athwartships, and therefore called "*In-and-out bolts.*"

Inner Post.—A piece of oak timber, brought on and fayed to the fore side of the main stern-post, for the purpose of seating the transoms upon it. It is a great security to the ends of the planks, as the main post is seldom sufficiently afore the rabbet for that purpose, and is also a great strengthener to that part of the ship.

Keel.—The main and lowest timber of a ship, extending longitudinally from the stem to the stern-post. It is formed of several pieces, which are scarphed together endways, and form the basis of the whole structure. Of course, it is usually the first thing laid down upon the blocks for the construction of the ship.

Keelson, or, more commonly, Kelson.—The timber, formed of long square pieces of oak, fixed within the ship exactly over the keel (and which may therefore be considered as the counterpart of the latter), for binding and strengthening the lower part of the ship; for which purpose it is fitted to, and laid upon, the middle of the floor timbers, and bolted through the floors and keel.

Knees.—The crooked pieces of oak timber by which the ends of the beams are secured to the sides of the ship. Of these, such as are fayed vertically to the sides are called *Hanging-Knees*, and such as are fixed parallel to or with the hang of the deck, are called *Lodging-Knees*. Knees are now usually of wrought iron; there are several kinds, as clutch-knees, horn-knees, plate-knees, etc.

Knee of the Head.—The large flat timber fayed edgeways upon the fore-part of the stem. It is formed by an assemblage of pieces of oak, coaked or tabled together edgewise by reason of its breadth, and it projects the length of the head. Its fore part should form a handsome serpentine line or inflected curve. The principal pieces are named the *mainpiece and lacing*.

Knightheads.—Large oak timbers, fayed and bolted on each side of the stem, the heads of which run up on each side sufficiently far to support the bowsprit.

Knuckle.—A sudden angle made on some timbers by a quick reverse of shape, as the knuckle of the floor, counter-timber, etc.

Laborsome.—Subject to *labor* or to pitch and roll violently in a heavy sea, by which the masts and even the hull may be endangered; for by a series of heavy rolls the rigging becomes loosened, and the masts at the same time may strain upon the shrouds with an effort which they will be unable to resist; to which may be added that the continual agitation of the vessel loosens her joints and makes her extremely leaky.

Landing Strake.—The upper strake but one in a boat.

To Lap Over or Upon.—The mast carlings are said to lap upon the beams by reason of their great depth, and head-ledges at the ends lap over the coamings.

Lap-Sided.—A term expressive of the condition of a vessel when she will not swim upright, owing to her sides being unequal.

Launch.—The slip or descent on which the ship is built, including the whole machinery of launching.

Launching Planks.—A set of planks mostly used to form the platform on each side of the ship whereon the bilgeways slide for the purpose of launching.

Laying-Off, or Laying-Down.—The act of delineating the various parts of the ship, to its true size, upon the mould-loft floor, from the draught given for the purpose of making the moulds.

Ledges.—Oak or fir scantling used in framing the decks, which are let into the carlings athwartships. The ledges for gratings are similar, but arch or round up agreeably to the head-ledges.

Lengthening.—The operation of separating a ship athwartships and adding

a certain portion to her length. It is performed by clearing or driving out all the fastenings in wake of the butts of those planks which may be retained, and the others are cut through. The after end is then drawn apart to a limited distance, equal to the additional length proposed. The keel is then made good, the floors crossed, and a sufficient number of timbers raised to fill up the vacancy produced by the separation. The kelson is then replaced to give good shift to the new scarphs of the keel, and as many beams as may be necessary are placed across the ship in the new interval, and the planks on the outside are replaced with a proper shift. The shelf, clamps and footwaling within the ship are then supplied, the beams kneed, and the ship completed in all respects as before.

To Let-in.—To fix or fit one timber or plank into another, as the ends of carlings into the beams, and the beams into the shelf or clamps, vacancies being made in each to receive the other.

Level Lines.—Lines determining the shape of a ship's body horizontally, or square from the middle line of the ship.

Limber-Passage.—A passage or channel formed throughout the whole length of the floor, on each side of the kelson, for giving water a free communication to the pumps. It is formed by the LIMBER-STRAKE on each side, a thick strake wrought next the kelson, from the upper side of which the depth in the hold is always taken. This strake is kept at about eleven inches from the kelson, and forms the passage fore and aft which admits the water with a fair run to the pump-well. The upper part of the limber-passage is formed by the LIMBER-BOARDS or plates, which are made to keep out all dirt and other obstructions. These boards are composed of iron plates, or else of short pieces of oak plank, one edge of which is fitted by a rabbet into the limber-strake, and the other edge beveled with a descent against the kelson. They are fitted in short pieces, for the convenience of taking up any one or more readily, in order to clear away any obstruction in the passage. When the limber-boards are fitted, care should be taken to have the butts in those places where the bulkheads come, as there will be then no difficulty in taking those up which come near the bulkheads. A hole is bored in the middle of each butt, to admit the end of a crow for prizing it up when required. To prevent the boards from being displaced, each should be marked with a line corresponding with one on the limber-strake.

Limber-Holes are square grooves cut through the underside of the floor timber, about nine inches from the side of the keel on each side, through which water may run toward the pumps, in the whole length of the floors. This precaution is requisite in merchant ships only, where small quantities of water, by the heeling of the ship, may come through the ceiling and damage the cargo. It is for this reason that the lower futtocks of merchant ships are cut off short of the keel.

Lips of Scarphs.—The substance left at the ends, which would otherwise become sharp, and be liable to split, and in other cases could not bear caulking, as the scarphs of the keel, stem, etc.

Lugger.—A vessel having one, two or three masts, lateen-rigged.

Main Breadth.—The broadest part of the ship at any particular timber or frame, which is distinguished on the sheer-draft by the upper and lower heights of breadth-lines.

Main-Wales.—The lower wales, which are generally placed on the lower breadth, and so that the main deck knee-bolts may come into them.

Mallet.—A large wooden hammer, used by caulkers.

Manger.—An apartment extending athwart the ship, immediately within the hawse-holes. It serves as a fence to interrupt the passage of water which may come in at the hawse-holes or from the cable when heaving in; and the water thus prevented from running aft is returned into the sea by the manger-scuppers, which are larger than the other scuppers on that account.

Mauls.—Large hammers used for driving treenails, having a steel face at one end and a point or pen drawn out at the other. Double-headed mauls have a steel face at each end of the same size, and are used for driving bolts, etc.

Meta-Centre.—That point in a ship above which the centre of gravity of weight must by no means be placed, because if it were the vessel would at once overset. The *meta-centre*, which has also been called the *shifting-centre*, depends upon the situation of the centre of buoyancy, for it is that point where a vertical line drawn from the centre of buoyancy cuts a line passing through the centre of gravity perpendicular to the keel.

Middle Line.—A line dividing the ship exactly in the middle. In the horizontal or half-breadth plan it is a right line bisecting the ship from the stem to the stern-post; and in the plane of projection, or body plan, it is a perpendicular line bisecting the ship from the keel to the height of the top of the side.

Momenta, or Moments.—The plural of *Momentum*.

Momentum of a heavy body, or of any extent considered as a heavy body, is the product of the weight multiplied by the distance of its centre of gravity from a certain point, assumed at pleasure, which is called the centre of the momentum, or from a line which is called the axis of the momentum.

Mortise.—A hole or hollow made of a certain size and depth in a piece of timber, etc., in order to receive the end of another piece, with a tenon fitted exactly to fill it.

Moulds.—Pieces of deal or board made to the shape of the lines on the mould-loft floor, as the timbers, harpins, ribbands, etc., for the purpose of cutting out the different pieces of timber, etc., for the ship. Also the thin, flexible pieces of pear tree or box used in constructing the draughts and plans of ships, which are made in various shapes, viz.: to the segments of circles from 1 foot to 22 feet radius, increasing 6 inches on each edge, and numerous elliptical curves, with other figures.

Moulded.—Cut to the mould. Also, the size or bigness of the timbers the way the mould is laid. *See* SIDED.

Nails.—Iron pins of various descriptions for fastening board, plank or iron work, viz.: *Deck nails* or *spike nails*, which are from four inches and a half to twelve inches long, have snug heads, and are used for fastening planks and the flat of the decks. *Weight nails* are similar to deck nails, but not so fine, have square heads, and are used for fastening cleats, etc. *Ribband nails* are similar to weight nails, with this difference—that they have large round heads, so as to be more easily drawn. They are used for fastening the ribbands, etc. *Clamp nails* are short, stout nails, with large heads, for fastening iron clamps. *Port nails*, double and single, are similar to clamp nails, and used for fastening iron work. *Rudder nails* are also similar, but used chiefly for fastening the pintles and braces. *Filling nails* of cast iron were formerly driven very thick in

the bottom planks, instead of copper sheathing; while smaller nails were used to fasten wood sheathing on the ship's bottom, to preserve the plank and prevent the filling nails from tearing it too much.* *Nails of sorts* are 4, 6, 8, 10, 24, 30 and 40-penny nails, all of different lengths, and used for nailing boards, etc. *Scupper nails* are short nails, with very broad heads, used to nail the flaps of the scuppers. *Lead nails* are small round-headed nails, for nailing lead. *Flat nails* are small, sharp-pointed nails, with flat, thin heads, for nailing the scarphs of moulds. *Sheathing nails*, for nailing copper sheathing, are of metal, cast in moulds, about one inch and a quarter long; the heads are flat on the upper side and countersunk below; the upper side is polished to obviate the adhesion of weeds. *Boat nails*, used by boat-builders, are of various lengths, generally rose-headed, square at the points, and made both of copper and iron.

Nog.—A short treenail that projects, to keep in its place any timber, or that is driven in to fasten the heels of shores, etc.

Oakum.—Old rope, untwisted and loosened like hemp, in order to be used in caulking.

To Over-Launch.—To run the butt of one plank to a certain distance beyond the next butt above or beneath it, in order to make stronger work.

Paddle-Beams.—Two large beams extending out from the sides of paddle-wheel steamers sufficiently far to receive the *spring* beams, which are dove-tailed to them. Frames are thus formed on which the paddle-boxes are erected. These beams are secured with large hanging-knees, both inside and out—those on the outside being formed with spurs.

Palleting.—A slight platform, made above the bottom of the magazine, to keep the powder-tanks from moisture.

Palls.—Stout pieces of iron, so placed near a capstan or windlass as to prevent a recoil, which would overpower the men at the bars when heaving.

Partners.—Those pieces of plank, etc., fitted into a rabbet in the mast or capstan carlings, for the purpose of wedging the mast and steadying the capstan. Also any plank that is thick, or above the rest of the deck, for the purpose of steadying whatever passes through the deck, as the pumps, bowsprit, etc.

To Pay.—To lay on a coat of tar, etc., with a mop or brush, in order to preserve the wood and keep out water. When one or more pieces are scarphed together, as the beams, etc., the inside of the scarphs are payed with tar as a preservative, and the seams, after they are caulked, are payed with pitch to keep the water from the oakum, etc.

Pink.—A ship with a very narrow, round stern; whence all vessels, however small, having their sterns fashioned in this manner, are said to be *pink-sterned*.

Pintles.—Straps of mixed metal or of iron, fastened on the rudder in the same manner as the braces on the stern-post, having a stout pin or hook at the ends, with the points downward, to enter in and rest upon the braces on which the rudder traverses or turns, as upon hinges, from side to side. Sometimes one or two are shorter than the rest, and work in a socket-brace, whereby the rudder turns easier. The latter are called *dumb-pintles*. Some are bushed.

Pitch.—Tar, boiled to a harder and more tenacious substance.

Pitching.—The inclination or vibration of the ship lengthwise about her centre of gravity, or the motion by which she plunges her head and after

* Obsolete.

part alternately into the hollow of the sea. This is a very dangerous motion, and when considerable not only retards the ship's way, but endangers the masts and strains the vessel.

Plank.—All timber from one and a half to four inches in thickness has this name given to it, except fir, which, to three inches in thickness, is frequently called deal.

Planking.—Covering the outside of the timbers with plank, sometimes quaintly called *skinning*, the plank being the outer coating when the vessel is not sheathed.

Plank-Sheers, or Plank-Sheer.—The pieces of plank laid horizontally over the timber-heads of the quarter deck and forecastle, for the purpose of covering the top of the side; hence sometimes called covering-boards.

Point-Velique.—That point where, in a direct course, the centre of effort of all the sails should be found.

Poppets.—Those pieces (mostly of pine or fir) which are fixed perpendicularly between the ship's bottom and the bilgeways, at the fore and aftermost parts of the ship, to support her in launching.

Port-Stopper or Shutter.—The heavy masses of iron used to close the ports of an iron-clad.

Preventer-Bolts.—The bolts passing through the lower end of the preventer-plates, to assist the chain-bolts in heavy strains.

Preventer-Plates.—Short plates of iron bolted to the side at the lower part of the chains, as extra security.

Pump.—The machine fitted in the wells of ships to draw water out of the hold.

Pump Cisterns.—Cisterns fixed over the heads of the pumps to receive the water until it is conveyed through the sides of the ship by the pump-dales.

Pump-Dales.—Pipes fitted to the cisterns to convey the water from them through the ship's sides.

Quarter Galleries.—The projections from the quarters abaft, fitted with sashes and ballusters, and intended both for convenience and ornament to the after part of the ship.

Quick-Work.—A term given to the strakes which shut in between the spirketing and the clamps. By quick-work was formerly meant all that part of a merchant vessel below the level of the water when she is laden.

To Quicken.—To give anything a greater curve. For instance, "*To quicken the sheer*" is to shorten the radius by which the curve is struck. This term is therefore opposed to straightening the sheer.

Rabbet.—A joint made by a groove or channel in a piece of timber, cut for the purpose of receiving and securing the edge or ends of the planks, as the planks of the bottom into the keel, stem or stern-post, or the edge of one plank into another.

Rag-Bolt.—A sort of bolt having its point jagged or barbed, to make it hold the more securely.

Rake.—The overhanging of the stem or stern beyond a perpendicular with the keel, or any part or thing that forms an obtuse angle with the horizon.

Ram-Line.—A small rope or line, sometimes used for the purpose of forming the sheer or hang of the decks, for setting the beams fair, etc.

Razing.—The act of marking by a mould on a piece of timber, or any marks made by a tool called a *razing-knife* or *scriber*.

Rate.—The denomination of different classes of ships of war according to their tonnage, weight of metal, etc.

To Reconcile.—To make one piece of work answer fair with the moulding or shape of the adjoining piece, and more particularly in the reversion of curves.

Reeming.—A term used by caulkers for opening the seams of the planks, that the oakum may be more readily admitted.

Reeming-Irons.—The large irons used by caulkers in opening the seams.

Rends.—Large open splits or shakes in timber, particularly in plank, occasioned by its being exposed to the wind or sun, etc.

Ribbands.—The longitudinal pieces of yellow pine or fir, about five inches square, nailed to the timbers of the square-body (those of the same description in the cant-body being shaped by a mould, and called *harpins*), to keep the body of the ship together and in its proper shape until the plank is brought on. The shores are placed beneath them. They are removed entirely when the planking comes on. The difference between *cant-ribbands* and *square* or *horizontal ribbands* is, that the latter are only ideal, and used in laying-off.

Ribband-Lines.—The same with diagonal lines.

Rising.—A term derived from the shape of a ship's bottom in general, which gradually narrows or becomes sharper toward the stem and the stern-post. On this account it is that the floor toward the extremities of the ship is raised or lifted above the keel; otherwise the shape would be so very acute as not to be provided from timber with sufficient strength in the middle or cutting-down. The floor timbers forward and abaft, with regard to their general form and arrangement, are therefore gradually lifted or raised upon a solid body of wood, called the *dead* or *rising wood*, which must, of course, have more or less rising as the body of the ship assumes more or less fullness or capacity. *See* DEAD RISING.

The Rising of Boats is a narrow strake of board fastened inside to support the thwarts.

Rising Floors.—The floors forward and abaft, which, on account of the rising of the body, are the most difficult to be obtained, as they must be deeper in the throat or at the cutting-down to preserve strength.

Rising-Line.—An elliptical line, drawn on the plan of elevation, to determine the sweep of the floor-heads throughout the ship's length, which accordingly ascertains the shape of the bottom with regard to its being full or sharp.

Rolling.—That motion by which a ship vibrates from side to side. Rolling is therefore a sort of revolution about an imaginary axis, passing through the centre of gravity of the ship; so that the nearer the centre of gravity is to the keel the more violent will be the roll, because the centre about which the vibrations are made is placed so low in the bottom that the resistance made by the keel to the volume of water which it displaces in rolling bears very little proportion to the force of the vibration above the centre of gravity, the radius of which extends as high as the mast-heads. But if the centre of gravity is placed higher above the keel, the radius of the vibration will not only be diminished, but such an additional force to oppose the motion of rolling will be communicated to that part of the ship's bottom as may contribute to diminish this movement considerably. It may be observed that with respect to the formation of a ship's body that shape which approaches nearest to a circle is the

most liable to roll, as it is evident that if this be agitated in the water it will have nothing to restrain it, because the rolling or rotation about its centre displaces no more water than when it remains upright; and hence it becomes necessary to increase the depth of the keel, the rising of the floors and the deadwood afore and abaft.

Room-and-Space.—The distance from the moulding edge of one timber to the moulding edge of the next timber, which is always equal to the breadth of two timbers, and two to four inches more. The room and space of all ships that have ports should be so disposed that the scantling of the timber on each side of the lower ports and the size of the ports fore and aft may be equal to the distance of two rooms and spaces.

Roughtree Rails.—In men-of-war, the broad plank running fore and aft, covering the heads of the top-timbers, thus forming the bottom of the hammock netting. In merchant vessels, the rails along the waist and quarters, nearly breast high, to prevent persons from falling overboard. This term originated from the practice in merchant vessels of carrying their rough or spare gear in crutch-irons along their waist.

Rudder.—The machine by which the ship is steered.

Rudder-Chocks.—Large pieces of fir to fay or fill up the excavation on the side of the rudder in the rudder-hole, so that the helm being in midships the rudder may be fixed; and supposing the tiller broke, another might thus be replaced.

Run.—The narrowing of the ship abaft, as of the floor toward the stern-post, where it becomes no broader than the post itself. This term is also used to signify the running or drawing of a line on the ship or mould-loft floor, as "to *run* the wale-line," or deck-line, etc.

Sampson-Knee, or Bitt Standard.—A knee used to strengthen the riding bitts.

Scantling.—The dimensions given for the timbers, planks, etc. Likewise all quartering under five inches square, which is termed scantling; all above that size is called *carling.*

Scarphing.—The letting of one piece of timber or plank into another with a lap, in such a manner that both may appear as one solid and even surface, as keel-pieces, stem-pieces, clamps, etc.

Schooner.—A vessel with two or three masts, with fore-and-aft sails set on gaffs. A topsail schooner has a fore-topsail, and sometimes a fore-topgallant sail.

Scuppers.—Lead pipes let through the ship's side to convey the water from the decks.

Scuttle.—An opening in the deck smaller than a hatchway.

Seams.—The openings between the edges of the planks when wrought.

Seasoning.—A term applied to a ship kept standing a certain time after she is completely framed and dubbed out for planking, which should never be less than six months, when circumstances will permit. *Seasoned plank or timber* is such as has been cut down and sawed out one season at least, particularly when thoroughly dry and not liable to shrink.

Seating.—That part of the floor which fays on the deadwood, and of a transom which fays against the post.

Sending or 'Scending.—The act of pitching violently into the hollows or intervals of the waves.

Setting or Setting-to.—The act of making the planks, etc., fay close to the timbers, by driving wedges between the plank, etc., and a wrain staff. Hence we say, "set or set away," meaning to exert more strength. The power or engine used for the purpose of setting is called a SETT, and is composed of two ring-bolts and a wrain staff, cleats and lashings.

Shaken or Shaky.—A natural defect in plank or timber when it is full of splits or clefts, and will not bear fastening or caulking.

Sheathing.—A thin sort of doubling or casing of yellow pine board or sheet copper, and sometimes of both, over the ship's bottom, to protect the planks from worms, etc. Tar and hair, or brown paper dipped in tar and oil, is laid between the sheathing and the bottom.

Sheer.—The longitudinal curve or hanging of a ship's side in a fore-and-aft direction.

Sheer-Draught.—The plan of elevation of a ship, whereon is described the outboard works, as the wales, sheer-rails, ports, drifts, head, quarters, post and stem, etc., the hang of each deck inside, the height of the water-lines, etc.

Sheer-Strake.—The strake or strakes wrought in the topside, of which the upper edge is wrought well with the top-timber line or top of the side, and the lower edge kept well with the upper part of the upper deck ports in midships, so as to be continued whole fore and aft, and not cut by the ports. It forms the chief strength of the upper part of the topside, and is therefore always worked thicker than the other strakes, and scarphed with hook and butt between the drifts.

Shelf.—Timbers worked fore and aft, in some ships, for the beams of the several decks to rest on.

Shift.—A term applied to the disposition of the butts or scarphs of plank or timber, that they may over-launch each other without a reduction in length, so as to gain the most strength.

Siding or Sided.—The size or dimensions of timber the contrary way to the moulding or moulded side.

Sills or Cills.—The short plank forming the upper and lower parts of the ports.

Sirmarks.—The different places marked upon the moulds where the respective bevelings are to be applied, as the lower sirmark, floor sirmark, etc.

Skeg.—The after end of the keel, or the part on which the stern-post rests. The iron *shoe* on which the heel of an equipoise rudder rests.

Slices.—Wedges used in connection with the poppets in launching.

Sliding Planks are the planks upon which the bilgeways slide in launching.

Slip.—The foundation laid for the purpose of building the ship upon and launching her.

To Snape.—To hance or bevel the end of anything so as to fay upon an inclined plane.

Snying.—A term applied to planks when their edges round or curve upward. The great sny occasioned in full bows or buttocks is only to be prevented by introducing steelers.

Specific Gravity.—The comparative difference in the weight or gravity of

two bodies of equal bulk; hence called also relative or comparative gravity, because we judge of it by comparing one body with another.

A TABLE OF SPECIFIC GRAVITIES.

Lead	11,325	Sea Water	1030
Fine Copper	9000	Tar	1015
Gun Metal	8784	River Water	1009
Fine Brass	8350	Rain Water	1000
Wrought Iron.......from 7827 to	7645	Oak	925
Cast Iron	7425	Ash	800
Roman Cement	1800	White Oak	714
Sand	1520	Beech	700
Lignum Vitæ	1327	Elm	600
Ebony	1177	Fir	548
Pitch	1150	Norway Pine	514
Rosin	1100	Yellow Pine	451
Mahogany	1063	Cork	240
Box Wood	1030	Common Air	1.232

These numbers being the weight of a cubic foot, or 1728 cubic inches, of each of the bodies in avoirdupois ounces, by proportion the quantity in any other weight, or the weight of any other quantity, may be readily known.

For example.—Required the content of an irregular piece of oak, which weighs 76 lbs., or 1216 oz.

	Sp. gr. oz.		wt. oz.		cub. in.		cub. in.	
Here as	925	:	1216	: :	1728	:	2271	= 1 ft. 543 inches cubic, the contents.

Spirketing.—A thick strake or strakes wrought withinside upon the ends of the beams or waterways. In ships that have ports, the spirketing reaches from the waterways to the upper side of the lower sill, which is sometimes of two strakes, wrought anchor-stock fashion; in this case, the planks should always be such as will work as broad as possible, admitting the butts be about six inches broad.

Sprung.—A term indicating that plank, etc., is strained so much in working as to crack or fly open.

Spurnwater.—A channel left above the ends of a deck, to prevent water from coming any further.

Square-Body.—The figure which comprehends all the timbers whose areas or planes are perpendicular to the keel, which is all that portion of a ship between the cant-bodies. *See* BODIES.

Square-Timbers.—The timbers which stand square with, or perpendicular to, the keel.

Square-Tuck.—A name given to the after part of a ship's bottom when terminated in the same direction up and down as the wing-transom, the planks of the bottom ending in a rabbet at the foreside of the fashion-piece; whereas ships with a buttock are round or circular, and the planks of the bottom end upon the wing-transom.

Stability.—That quality which enables a ship to keep herself steadily in the water without rolling or pitching. Stability in the construction of a ship is only to be acquired by fixing the centre of gravity at a certain distance below

the meta-centre, because the stability of the vessel increases with the altitude of the meta-centre above the centre of gravity. But when the meta-centre coincides with the centre of gravity, the vessel has no tendency whatever to remove out of the situation into which it may be put. Thus, if the vessel be inclined either to the starboard or port side, it will remain in that position till a new force is impressed upon it. In this case, therefore, the vessel would not be able to carry sail, and is consequently unfit for the purposes of navigation. If the meta-centre falls below the common centre of gravity, the vessel will immediately overset.

Stanchions.—Upright posts of timber or iron to support the beams, decks, rails, etc.

Steeler.—A name given to the foremost or aftermost plank, in a strake which drops short of the stem and stern-post, and of which the end or butt nearest the rabbet is worked very narrow and well forward or aft. Their use is to take out the snying edge occasioned by a full bow or sudden circular buttock.

Stem.—The main timber at the fore part of the ship, formed by the combination of several pieces into a curved shape and erected vertically to receive the ends of the bow-planks, which are united to it by means of a rabbet. Its lower end scarphs or boxes into the keel, through which the rabbet is also carried, and the bottom unites in the same manner.

Stemson.—A piece of compass timber, wrought on the after part of the apron inside, the lower end of which scarphs into the keelson. Its upper end is continued as high as the middle or upper deck, and its use is to succor the scarphs of the apron, as it does those of the stem.

Steps of the Masts.—The steps into which the heels of the masts are fixed are large pieces of timber. Those for the main and foremasts are fixed across the keelson, and that for the mizzen-mast upon the lower deck-beams. The holes or mortises into which the masts step should have sufficient wood on each side to accord in strength with the tenon left at the heel of the mast, and the hole should be cut rather less than the tenon, as an allowance for shrinking.

Steps for the Ship's Side.—The pieces of quartering, with mouldings, nailed to the sides amidship, about nine inches asunder, from the wales upward, for the convenience of persons getting on board.

Stern Frame.—The strong frame of timber composed of the stern-post, transoms and fashion-pieces, which form the basis of the whole stern.

Stern-Post.—The principal piece of timber in the stern frame on which the rudder is hung, and to which the transoms are bolted. It therefore terminates the ship below the wing-transom, and its lower end is tenoned into the keel.

Stiff.—Stable; steady under canvas.

Stiving.—The elevation of a ship's cathead or bowsprit, or the angle which either makes with the horizon; generally called steeve.

Stoppings-Up.—The poppets, timber, etc., used to fill up the vacancy between the upper side of the bilgeways and the ship's bottom, for supporting her when launching.

Straight of Breadth.—The space before and abaft dead-flat, in which the ship is of the same uniform breadth, or of the same breadth as at ⊗ or dead-flat. *See* DEAD-FLAT.

Strake.—One breadth of plank wrought from one end of the ship to the other, either within or outboard.

Tabling.—Letting one piece of timber into another by alternate scores or projections from the middle, so that it cannot be drawn asunder either lengthwise or sidewise.

Taffarel or Taff-Rail.—The upper part of the ship's stern, usually ornamented with carved work or mouldings, the ends of which unite to the quarter-pieces.

Tasting of Plank or Timber.—Chipping it with an adze, or boring it with a small auger, for the purpose of ascertaining its quality or defects.

To Teach.—A term applied to the direction that any line, etc., seems to point out. Thus we say, "Let the line or mould *teach fair* to such a spot, raze," etc.

Tenon.—The square part at the end of one piece of timber, diminished so as to fix in a hole of another piece, called a mortise, for joining or fastening the two pieces together.

Thickstuff.—A name for sided timber exceeding four inches, but not being more than twelve inches in thickness.

Tholes, or Thole-Pins.—The battens or pins forming the row-locks of a boat.

Throat.—The inside of knee timber at the middle or turn of the arms. Also the midship part of the floor timbers.

Thwarts.—The seats in a boat on which the oarsmen sit.

Timber.—(*Material for ship-building.*) Timber is generally distinguished into rough, square or hewn, sided and converted timber. *Rough timber* is the timber to its full size as felled, with lop, top and bark off. *Hewn timber* is timber squared for measurement. *Sided timber* is the tree of the full size, one way, as it is felled, but with slabs taken off from two of its sides and made straight; on the other side, at the middle of the tree, it must be one-eighth of its depth, or siding more than its siding between the wanes. *Converted timber* is timber cut for different purposes, and distinguished into thickstuff, plank, board, carling and scantling. The timber in most general use in this country is live-oak, white oak, yellow and spruce pine, red pine, fir, hackmatack, ash and white pine; cedar being used for boats.

Timber for Masts, Yards and Spars.—Pieces of yellow, spruce or red pine timber. Those pieces suitable for masts are called *sticks*. Special care is required in their inspection to see that they are sound. They are divided into squared sticks, called *inch-masts*, classed according to the number of inches at the side, and into round sticks, classed according to their girth at the butt, in hands of four inches, called *hand-masts* if their girth is not less than six hands, and *spars* if their girth is less than six hands. Spars are sub-divided into classes, as follow:

Name.	Length.	Girth at the Butt.
Cant spars	From 33 to 35 feet.	From 6 to 5 hands.
Barling spars	28 to 30 feet.	5 to 4 hands.
Boom spars	20 to 25 feet.	4 to 3 hands.
Middling spars	16 to 20 feet.	3 to 2 hands.
Small spars	11 to 16 feet.	1 to 2 hands.

Immersion in mud is considered the best mode of preserving spar or mast timber until needed for use.

Timber-Heads.—Timbers left clear for lashing the anchors, making fast stoppers, shank-painters, etc.

Timber-and-Room.—*See* ROOM-AND-SPACE.

Tonnage.—The cubical contents or burthen of a ship in tons. There are several ways of estimating tonnage, as builder's measurement, custom-house measurement, and tonnage by displacement.

Top and Butt.—A method of working English oak plank so as to make good conversion. As the plank runs very narrow at the top, clear of sap, this is done by disposing the top end of every plank within six feet of the butt end of the plank above or below it, letting every plank work as broad as it will hold clear of sap, by which method only can every other seam produce a fair edge.

Top-Hamper.—All weight above the centre of gravity of the *vessel.* Generally used, however, to express unnecessary weight aloft.

Topside.—A name given to all that part of a ship's side above the main-wales.

Top-Timbers.—The timbers which form the topside. The first general tier which reach the top are called the long top-timbers, and those below are called the short top-timbers. *See* FRAMES.

Top-Timber Line.—The curve limiting the height of the sheer at the given breadth of the top-timbers.

Touch.—The broadest part of a plank worked top and butt, which place is six feet from the butt end. Or the middle of a plank worked anchor-stock fashion. Also the sudden angles of the stern-timbers at the counters, etc.

Trail-Boards.—A term for the carved work between the cheeks, at the heel of the figure.

Transom-Knee.—A knee used against the transom in square-sterned ships.

Transoms.—The 'thwartship timbers which are bolted to the stern-post in order to form the buttock, and of which the curves forming the *round aft* are represented on the horizontal or half-breadth plan of the ship.

Transom-Seat.—A transom fayed and bolted to the counter-timbers above the deck, generally at the height of the portsill.

Tread of the Keel.—The whole length of the keel upon a straight line.

Treenails.—Cylindrical oak pins driven through the planks and timbers of a vessel, to fasten or connect them together. These certainly make the best fastening when driven quite through, and caulked or wedged inside. They should be made of the very best oak or locust, cut near the butt, and perfectly dry or well-seasoned.

The Tuck.—The after part of the ship, where the ends of the planks of the bottom are terminated by the tuck-rail, and all below the wing-transom when it partakes of the figure of the wing-transom as far as the fashion-pieces. *See* SQUARE TUCK.

Tuck-Rail.—The rail which is wrought well with the upper side of the wing-transom, and forms a rabbet for the purpose of caulking the butt ends of the planks of the bottom.

Upright.—The position of a ship when she inclines neither to one side nor the other.

Wales.—The principal strakes of thickstuff wrought on the outside of the ship upon the main-breadth. Also those strakes wrought between the ports of a man-of-war, called the *channel-wales.* There are also in very large ships sheer-wales, middle-wales and main-wales.

Wall-Sided.—A term applied to the topsides of the ship when the main breadth is continued very low down and very high up, so that the topsides appear straight and upright like a wall.

Wash-Board.—A shifting strake along the topsides of a small vessel, used occasionally to keep out the sea.

Water-Lines, or Lines of Flotation.—Those horizontal lines, supposed to be described by the surface of the water on the bottom of a ship, and which are exhibited at certain depths upon the sheer-plan. Of these the most particular are those denominated the *light water-line* and the *load water-line;* the former, namely, the light water-line, being that line which shows the depression of the ship's body in the water when light or unladen, as when first launched; and the latter, which exhibits the same when laden with her guns and ballast, or cargo. In the half-breadth plan these lines are curves limiting the half-breadth of the ship at the height of the corresponding lines in the sheer-plan.

Waterways.—The edge of the deck next the timbers, which is wrought thicker than the rest of the deck, and so hollowed to the thickness of the deck as to form a gutter or channel for the water to run through to the scuppers.

Wedges.—Slices of wood driven in between the masts and their partners, to admit of giving rake if desired.

Whelps.—The brackets or projecting parts of the barrel of a capstan.

Whole-Moulded.—A term applied to the bodies of those ships which are so constructed that one mould made to the midship-bend, with the addition of a floor hollow, will mould all the timbers below the main-breadth in the square body.

Wings.—The places next the side upon the orlop, parted off in foreign ships of war, that the carpenter and his crew may have access round the ship in time of action, to plug up shot-holes, etc.

Wing-Transom.—The uppermost transom in the stern frame, upon which the heels of the counter-timbers are let in and rest. It is by some called the main-transom.

Wood-Lock.—A piece of elm or oak, closely fitted and sheathed with copper, in the throating or score of the pintle, near the load water-line, so that when the rudder is hung and the wood-lock nailed in its place, it cannot rise, because the latter butts against the under side of the brace and butt of the score.

Wrain-Bolt.—Ring-bolts used when planking, with two or more forelock holes in the end for taking in the set, as the plank, etc., works nearer the timbers.

Wrain-Stave.—A sort of stout billet of tough wood, tapered at the ends so as to go into the ring of the wrain-bolt, to make the setts necessary for bringing-to the planks or thickstuff to the timbers.

Yacht.—A small vessel (sailing or steam vessel), light and elegantly furnished for private parties of pleasure.

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